THE LUNAR CHRONOLOGY CAN NOT BE DIRECTLY SCALED TO THE ASTEROID BELT.

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Introduction: Schmedemann *et al.* [1] construct a crater chronology curve for Vesta assuming that (a) the primary source region of impactors in the inner Solar System is the main asteroid belt, and (b) that the Lunar chronology curve [2] can be scaled to Vesta using the current impact rate in the asteroid belt and appropriate adjustments for the crater production function due to the different impact velocities on Vesta and the Moon. A similar approach is also being used for Ceres [3]. Here we show that directly scaling the Lunar curve to Vesta and other asteroids in this manner implies an extremely intense collisional history for Vesta, and the entire asteroid belt, that is inconsistent with a range of fundamental constraints.

"Lunar-Like Chronology": Figure 1 shows the Lunar chronology curve for 1 km craters from [2] and the corresponding curve for Vesta calculated in [1], which they refer to as the "Lunar-like chronology." These curves show the total cumulative number of craters N that would be produced from a time T in the past to the present day (T=0), and can be used to convert a crater density into an absolute surface age. The curves are dashed prior to 4.1 Ga, as there are no good radiometric constraints from Lunar samples for that time period, although as we will show next, it is possible to set a minimum value for the Vesta curve based on asteroid belt constraints.

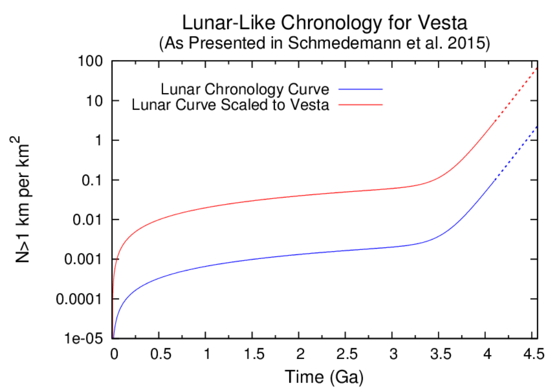

Figure 1

A More Realistic Assessment: We start with the derivative of the curves in Fig. 1, which gives the crater production rate dN/dT at time T. Figure 2 shows the normalized crater production rate dN^*/dT, which is normalized to 1 at the present time, for the Lunar-like curve from Fig. 1 as well as the model chronology curve for Vesta proposed by [4] and a linear chronology curve (where the mass of the asteroid belt remains constant with time). Because of the assumption that the primary impactors are asteroids themselves, this normalized impact rate must also be directly proportional to the mass of the asteroid belt. Hence, the curves in Fig. 2 also give M^*, the normalized mass of the asteroid belt (equal to 1 at the present time). While the Lunar chronology may be unconstrained prior to ~4.1 Ga, the asteroid belt chronology can be constrained by the fact that the asteroid belt must actually exist prior to 4.1 Ga, and at the very least would have had a constant mass prior to 4.1 Ga. Hence, the red curve in Fig. 2 is flat prior to 4.1 Ga.

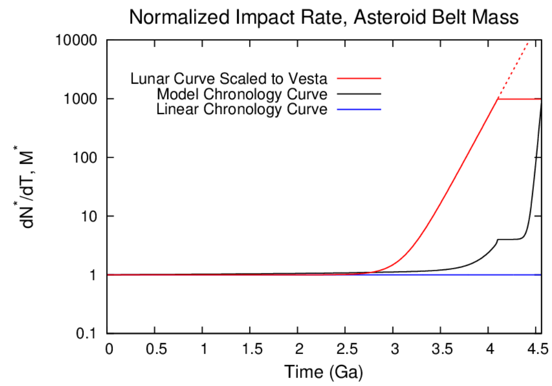

Figure 2

Figure 2 illustrates one of that main problems with the Lunar-like chronology, namely that the asteroid belt would have to be at least ~1000x its current mass for the first 400 Myr of Solar System history, in contrast to the model chronology curve of [4], where the belt undergoes an early rapid dynamical depletion event. Given reasonable estimates for the collisional strength of asteroidal material, such a massive belt would be substantially depleted through collisional grinding in much less than 400 Myr [eg. 5-8]. Adding more mass would not resolve this issue, as that would also increase the rate of collisional grinding. Simply put, the Lunar-like chronology requires a history for the asteroid belt that would not be stable against collisional grinding.

Integrating the curves in Fig. 2 gives the normalized chronology curves $N^*(T)$ shown in Fig. 3, which are similar to those shown in Fig. 1, although they are size-independent, have units of time (Ga), and are normalized to 1 at T=1 Ga. If the current production rate f(D) of a given size crater is known at the present, multiplying f(D) by $N^*(T)$ will give the number of those craters formed since time T in the past.

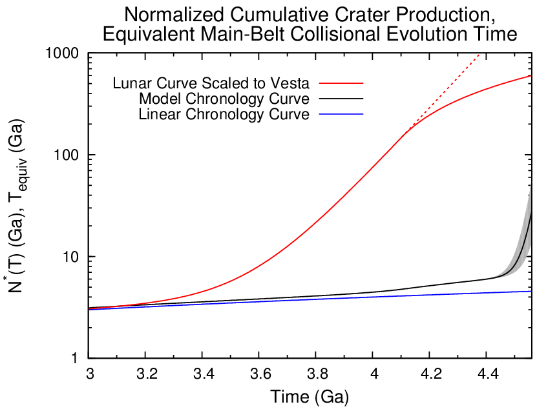

Figure 3

Another interpretation of the curves in Fig. 3 is that they show the equivalent time T_{equiv} that would have to elapse in a constant-mass asteroid belt to give the number of impacts (and the amount of collisional evolution) that occur in time T. For the linear chronology curve, where the belt has a constant mass, T_{equiv} = T by definition. For other cases, where the mass of the belt is initially larger than the present time, T_{equiv} > T.

[6,7] fit a collisional model of the main belt to a wide range of constraints including the main-belt and NEA size distributions, asteroid families, and the cosmic-ray exposure ages of meteorites, and find that these constraints are consistent with T_{equiv} of at most a few tens of Gyr, eg. a small initial mass of the asteroid belt, or more likely a rapid depletion of a larger initial mass. From Fig. 3, the Lunar-like curve implies a T_{equiv} of hundreds of Gyr, due to the large and long-lived initial mass of the belt that is required, and is thus wildly inconsistent with the constraints of [6,7].

Figure 4 shows the production rate of craters 200 km in diameter and larger on Vesta for the chronologies of [1] and [4]. The curves are offset by a factor of a few because [1] and [4] assume somewhat different crater production functions f(D). While [1] claim that nothing can be said about the cratering rate on Vesta prior to 4.1 Ga, it is immediately clear that even the most conservative estimate of a constant-mass asteroid belt prior to 4.1 Ga implies substantial early cratering in the Lunar-like chronology. From T=4.5 Ga to the present, roughly 60 basins larger than 200 km in diameter would be expected over the surface of Vesta. At least ten of these would be expected to be the size of Venenia (~400 km) and Rheasilvia (~500 km), or even larger. This is grossly inconsistent with the observed large crater distribution on Vesta, which is found to have approximately 5 and 10 craters larger than 200 km and 100 km, respectively [1,9]. While a few large craters may have formed in the past and been erased (perhaps by the subsequent formation of Rheasilvia and Venenia), there is no evidence that several tens of basins from 200 km to Rheasilvia-sized and larger could have formed. For example, the northern hemisphere lacks any large-scale diogenite signatures as seen in the Rheasilvia basin [10] and has a shape close to hydrostatic equilibrium (unlike the south which is heavily deformed by Rheasilvia and Venenia) [11].

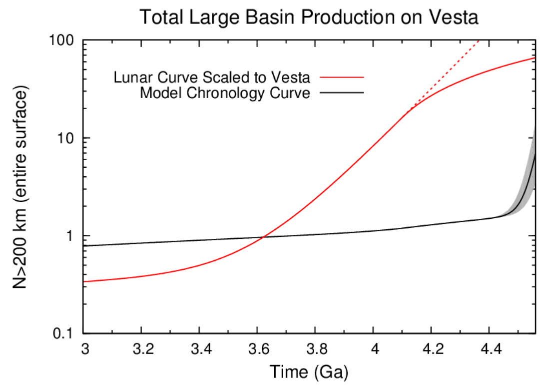

Figure 4

Summary: Schmedemann *et al.* [1] apply the Lunar chronology to Vesta using a simple scaling approach that does not take into account the actual physical behavior of the asteroid belt that would be required, in particular ignoring processes prior to 4.1 Ga. Adopting the simple assumption that the mass of the asteroid belt must have at the very least been constant prior to that time, we show that the Lunar-like chronology: (1) Requires an asteroid belt that has a mass of at least 1000x the current mass for the first 400 Myr, which would not survive against collisional grinding; (2) Implies a high level of collisional evolution in the asteroid belt that is inconsistent with a wide range of constraints as shown by [6,7]; and (3) Would result in many times more large (>200 km) impact basins on the surface of Vesta than are actually observed. We argue that the Lunar-like chronology of [1] is not a valid approach for estimating cratering ages on Vesta, Ceres or any other bodies in the asteroid belt.

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References: [1] Schmedemann *et al.* (2014), *PSS* **103**, 104. [2] Neukum *et al.* (2001), *Space. Sci. Rev.* **96**, 55. [3] Schmedemann *et al.* (2015), LPSC, 1418. [4] O'Brien *et al.* (2014), *PSS* **103**, 131. [5] Benz and Asphaug (1999), *Icarus* **142**, 5. [6] Bottke *et al.* (2005), *Icarus* **175**, 111. [7] Bottke *et al.* (2005), *Icarus* **179**, 63. [8] Bottke *et al.* (2007), *Icarus* **190**, 203. [9] Marchi *et al.* (2012), *Science* **336**, 690. [10] Ammannito *et al.* (2013), *MAPS* **48**, 2185. [11] Ermakov *et al.* (2014), *Icarus* **240**, 146.