SEASONAL VARIATION IN CURRENT MARTIAN IMPACT RATE. I. J. Daubar,[1] A. S. McEwen,[1] S. Byrne,[1] and M. R. Kennedy[2]. [1]Lunar & Planetary Laboratory, University of Arizona, Tucson, AZ, 85721 (ingrid@lpl.arizona.edu), [2]Malin Space Science Systems, PO Box 910148, San Diego, CA, 92191.

Background: Recent discoveries of craters currently forming on Mars [1-7] require both a "before" and an "after" image. The dates of these images constrain the time period in which the impact could have occurred. In many cases (~40% of the current database of 215 new impacts), those dates can be constrained to less than a martian year. These data can be used to examine possible variation in impact rate with season. For example, previous work [8] predicted a difference in the impactor populations at aphelion and perihelion as large as a factor of 20, due to the increased proximity of Mars to the main asteroid belt at aphelion. Here we update that prediction and test the hypothesis of an aphelion enhancement in the impact rate.

Updated estimate of seasonal enhancement: Using the most recent asteroid orbital data from [9], we calculate q (perihelion distance) for all currently known asteroids. A plot of the incremental number of asteroids with q is shown in Fig. 1, showing the maximum and minimum populations of potential impactors at martian aphelion and perihelion, respectively. The difference between the maximum and minimum populations is only a factor of 9 using this updated data set, rather than 20 as previously estimated [8].

This database of asteroids has not been observationally debiased; this estimate assumes there is little bias in the region of Mars's orbit. While the observational data may not be complete, ratioing the values reduces the effect of that incompleteness. If the amount of incompleteness is higher at larger distances as one might expect, then this estimate of the aphelion/perihelion ratio would be a conservative one.

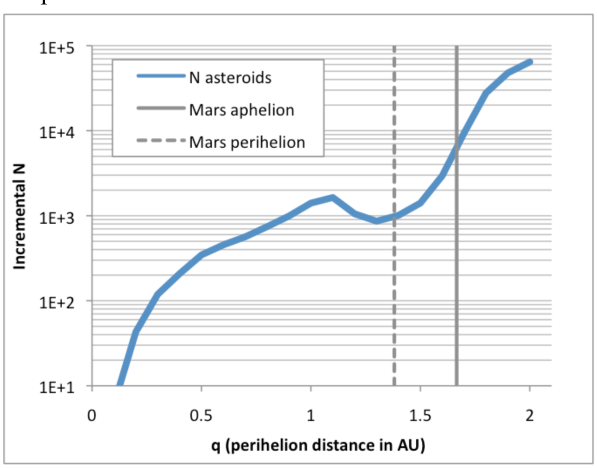

Fig. 1: Number of asteroids from [9] as a function of q (perihelion distance in AU). Perihelion distance q is binned in 0.1 AU increments. The farthest extents of Mars's orbit are also shown.

Seasonally-averaged impact variation: The factors of 20 and 9 describe the ratio between the impacting asteroid populations at the point of aphelion and at the point of perihelion. Since our impact data is not continuous at every Ls, we instead need to compare seasonally-averaged ratios. Assuming that the rate varies sinusoidally over the martian year, the number of impactors can be integrated separately over the perihelion half of the year and the aphelion half of the year to get a relative overall seasonal ratio of number of impacts. Using this method, an aphelion/perihelion difference of 20x in impactor populations is equivalent to a seasonal enhancement of only 3.7x in the impact rate, and an impactor population difference of 9x is equivalent to a seasonal enhancement of 3.1x in the impact rate.

Possible impact dates: Out of our database of 215 new dated impacts, only ~18% (38) are limited to have formed within a time period of less than half a martian year. We restrict our analysis to this subset of relatively well-constrained impacts. A histogram of possible formation dates of those 38 impacts is shown in Fig. 2. In this plot, each 20° L_s bin is incremented if the formation could possibly have occurred within that time; the amount by which the bin is incremented is scaled inversely to the number of bins the impact's before- and after-images span. For example, an impact that could have occurred in any of 4 bins is represented by an increment of 0.25 in each of those bins. Therefore more well-constrained impacts contribute more to this plot. The number of possible impacts in each bin is also scaled to the relative time (in Earth years) Mars spends in each L_s bin, since the bins are not evenly distributed in time.

Statistical test of enhancement: There is a clear seasonal trend visible in Fig. 2. When this set of impacts is separated into perihelion (161°-341° L_s) and aphelion (0°-161° and 341°-360° L_s) seasons, the aphelion enhancement is seen in the difference of mean values of possible impacts per year in each L_s bin between aphelion (25.2) and perihelion (13.7). This result is significant to a 98% confidence level using a two-tailed t-test ($t(8)=2.90$, $p=0.020$).

While we can confirm an aphelion seasonal enhancement in impacts of ~1.8x, a hypothesized 3.7x enhancement (20x asteroid population difference) can be ruled out with 97% confidence ($t(8)=2.61$, $p=0.031$). A 3.1x seasonal enhancement (9x asteroid population difference) is also unlikely ($t(8)=2.07$, $p=0.072$, 93% confidence). In other words, although an enhancement at aphelion does seem to be present, a difference in the aphelion impacting population of a factor of 9, let alone a factor of 20, is improbable according to these statistics.

Seasonal variation of area imaged: The data initially seem to clearly show an aphelion enhancement in the impact rate; however, that apparent increase is likely due to the increase in data volume downlinked to Earth during that season. An important factor in the likelihood of finding new craters is the area imaged during that time by the Context camera (CTX) [10] on the Mars Reconnaissance Orbiter (MRO), because most of the new impacts are discovered in CTX images. In recent years, the high data rate season for MRO has coincided roughly with aphelion [Fig. 2], which makes it difficult to distinguish the effects of a true impact rate enhancement. When the impact dates are scaled to the area imaged by CTX during that L_s range between 10°S-50°N latitude (since new impacts are mainly being discovered in the dusty north-mid-latitude regions of Mars), an aphelion impact rate enhancement is much less convincing [Fig 3]. Any seasonal enhancement (now only 1.2x) is only present at a 36% confidence level ($t(8)=0.48$, $p=0.64$). Higher levels of enhancement are even less likely.

There are two more convincing, but narrow, spikes in the impact rate ~Ls 320°-20° and 80°-140°. Possible explanations for increases at those times are unknown. Given our dating uncertainties and approximations in the area scaling, though, these spikes may not actually be significant.

Conclusions: Although there is a definite seasonal trend in observed new impacts, we are not yet able to distinguish a real trend in the current impact rate from effects related to the data gathering rate used in the discoveries. We see no evidence for the 20x impactor population difference predicted by [8], nor for our updated prediction of a 9x difference. With more new impacts continuously being discovered, we hope to improve our statistics of well-constrained events.

Discussion: If there really is no overall increase in the impact rate at aphelion, how can that be explained? It is conceivable that comets are a more important source of impactors than main belt asteroids. At least some of the impactors seem to have densities consistent with cometary material [11]. However, most researchers agree that the cratering SFD matches that of asteroids rather than comets [*e.g.* 8, 12].

Another possibility is that the observed asteroid population could be incomplete in such a way that the resulting seasonal enhancement in impact rates is much smaller than our estimates. The population difference would have to be much lower, though – it would have to be as low as ~3x to account for the seasonally averaged impact rate enhancement of 1.8x that we calculate before the area scaling is applied.

However, it is most likely that we are simply unable to see an enhancement due to the limitations of small-number statistics and impact dates that are not well-enough constrained.

References: [1] Malin M.C. *et al.* (2006) *Science*, 314, 1573-1577. [2] Ivanov B.A. *et al.* (2008) *LPS* XXXIX, 1402. [3] Daubar I.J. and McEwen A.S. (2009) *LPS* XL, 2419. [4] Kennedy M.R. and Malin M.C. (2009) *AGU Fall Meeting*, P43D-1455. [5] Daubar I.J. *et al.* (2010) *LPS* XLI, 1978. [6] Daubar I.J. *et al.* (2011) *LPS* XLII, 2232. [7] Daubar I.J. *et al.* (2011) *EPSC-DPS* 6. [8] Ivanov B.A. (2001) *SSR* 96, 87-104. [9] Bowell, E. (2012) http://asteroid.lowell.edu/ [10] Malin M.C. *et al.* (2007) *JGR* 112, 5. [11] Ivanov B.A. *et al.* (2011) *EPSC-DPS* 6. [12] Neukum G. *et al.* (2001) *SSR* 96, 55-86.

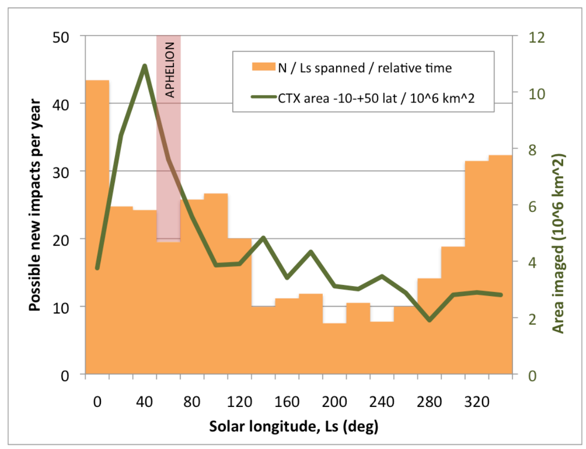

Fig. 2: Possible formation dates of 38 new dated impacts, each constrained to have formed in <180° L_s. Each impact's contribution to the histogram is scaled by the number of 20° L_s bins its formation could have spanned. Possible N impacts are also scaled to the relative time (Earth years) spent in each L_s bin. Area (10^6 km^2) imaged by the CTX instrument over the MRO mission between 10°S-50°N latitude is also plotted by L_s in, showing the peak of high data rate near aphelion.

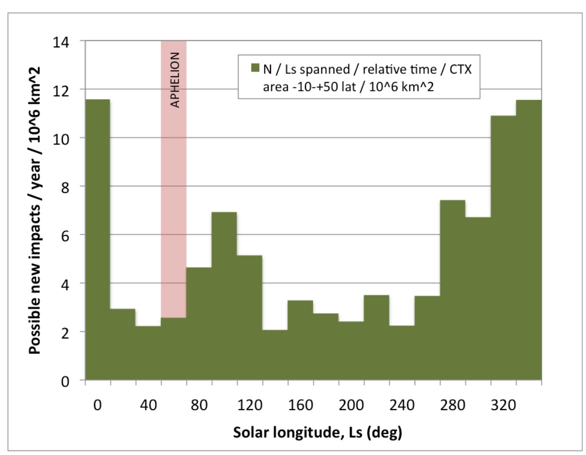

Fig. 3: Formation dates scaled to L_s range, relative time of L_s bin, and area (10^6 km^2) imaged by CTX between 10°S-50°N latitude.