VENUS AIRBURSTS: IMPLICATIONS FOR GLOBAL RESURFACING.

T. J. Austin[1]*, J. G. O'Rourke[1], N. Izenberg[2], E. A. Silber[3]. [1]Arizona State University, Tempe, AZ. [2]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD. [3]Sandia National Laboratories, Albuquerque, NM. *t.austin@asu.edu

Background: The Venusian impact record is consequential to interpretation of all geologic features on the planet. Fewer than 1000 impact craters exist on the surface—and their spatial distribution appears random overall. This record attests to an average surface age of ~300–750 Ma [1]. One popular interpretation consistent with these observations is a catastrophic (near-)global volcanic resurfacing event followed by a period of (relative) volcanic quiescence [1,2]. Gradual, equilibrium resurfacing could account for the cratering record as well [3,4]. These two end-member hypotheses paint disparate pictures of Venus overall. Differences between these two models include the global stratigraphy of geologic units, the internal structure of the crust and mantle, the amount of modern volcanic activity, and the habitability of Venus in the past. The unresolved conflict between these hypotheses ultimately hinges upon the inconclusive cratering record. However, craters are not the only impact features on Venus.

On worlds with substantial atmospheres, small meteors can break up explosively. Pressure waves may even act upon the surface if the airburst occurs in the lower atmosphere. Events on Earth, such as the 1908 Tunguska airburst, are sufficiently powerful to, say, flatten thousands of square kilometers of forest. The dense atmosphere of Venus allows airbursts strong enough to alter surface morphology. Indeed, previous studies attribute hundreds of radar albedo features, up to 300 kilometers in diameter, to airbursts [5] (Fig. 1).

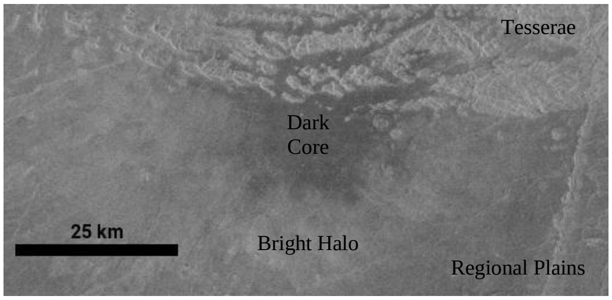

Figure 1: Pristine airburst scar ("splotch") on the boundary between Regional Plains and Tesserae (28.45°N, -111.59°E). The dark core and bright halo are only apparent on smooth Regional Plains terrain.

Wood (2000) [6] put forward the most mature model explaining the features of airburst scars (Fig. 2). Near "ground zero" of the airburst, the shockwave is strong enough to pulverize bedrock, creating a smooth, radar-dark surface. Radially out from this, the ground is scoured, forming a radar-bright halo. These formations are expected to have negligible relief, making them susceptible to even superficial resurfacing events [7]. These models do not explain some features, notably, the dark concentric rings observed on some airburst scars.

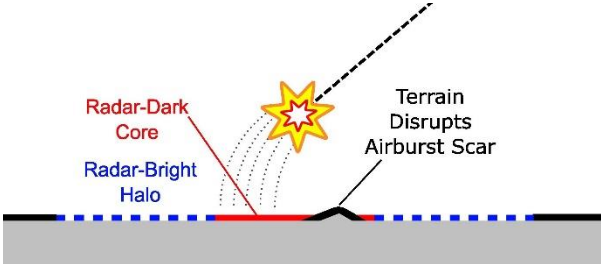

Figure 2: Emplacement of an airburst scar. The radar-dark core forms directly under the airburst and the radar-bright halo extends radially outward. Sharp terrain may disrupt the idealized surface pattern.

Our ultimate goal is to use observations of airburst scars, alongside impact craters, to test models of the history of volcanic resurfacing. To our knowledge, only one study in the mid-1990s attempted to integrate airburst scar distribution into the impact record [1]. However, this effort was almost entirely qualitative and used a database of scars that was perhaps over-inclusive. The distribution of airburst scars is obviously clustered, especially in contrast to craters on Venus (Fig. 3). Previous work assumed that highlands terrain somehow inhibits the formation, preservation, or observability of splotches, causing clustering [1,6]. However, whether terrain bias alone is sufficient to explain the clustering observed in airburst scars has not been fully tested.

Motivated by the pivotal role the impact record plays in the resurfacing debate and the lack of study on airburst scars in particular, we examined the distribution of airburst scars on the surface of Venus. In addition to the important implications for the whole of Venus evolution, this study will enhance understanding of meteor airbursts as a geologic process.

Methods: We used the pre-existing database from Strom et al. (1994) [1] as a guide to re-survey airburst scars on the 75m Magellan global radar mosaic. In addition to refining the scars' coordinates, we discovered nine more airburst scars. We discarded 118 of the 401 scars from the original database that resembled volcanic features or a single scar (rather than pair of scars)—or overlapped with impact craters. The total number of scars in our survey is thus 292. For comparison, a similar re-survey by Wood (2000) yielded

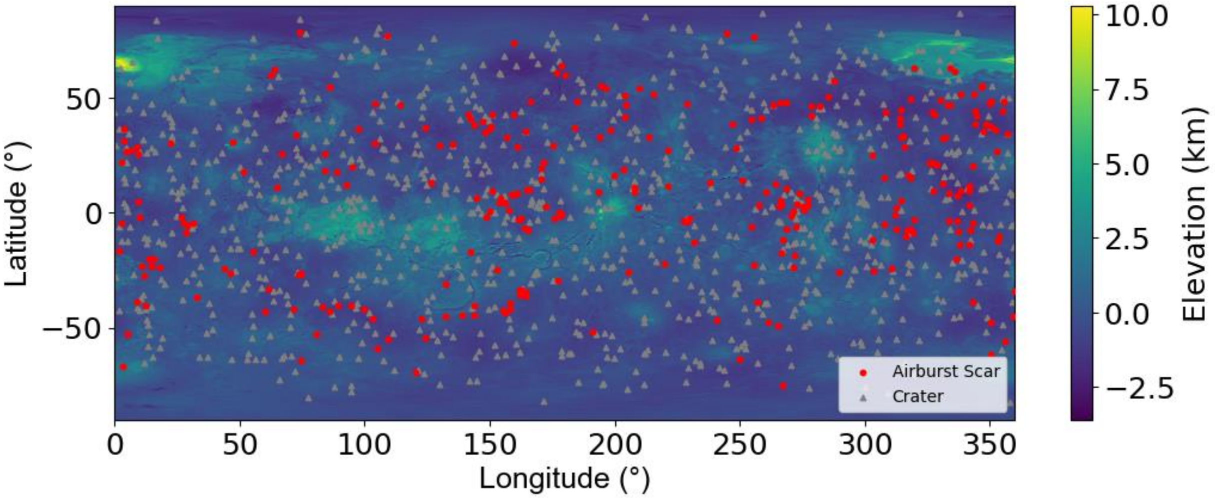

Figure 3: Distribution of impact features on an elevation map of Venus. Craters have an apparent random distribution spatially and by elevation. Airburst scars are nearly absent on rough, high-altitude terrain. Even when considering solely the low-elevation plains, there are strong clusters and broad gaps in airburst scar distribution.

262 airburst scars. We correlated the locations of our survey's airburst scars with geologic units defined by the Ivanov & Head (2011) [8] geologic map of Venus. We then compared clustering in Monte Carlo simulations of airburst distribution to our survey via statistical analysis (see O'Rourke et al. 2014 [4]).

Results: The low-elevation, low-relief Regional Plains contain ~70% of airburst scars. Generally, more rugged and radar-bright geologic units preserve fewer scars (Table 1). The difference in observability is apparent with individual scars emplaced over multiple terrain types (Fig. 1). Using a simple assumption that the Regional Plains represent 100% preservation, ~160 airburst scars are "missing" from Venus's surface.

	Coverage (%)	# per Mil km^2	# 'Missing'
Regional Plains	48.5	0.905	0
Other Plains	12.2	0.695	9
Shield Volcanoes	18.1	0.420	40
Tectonic Provinces	15.2	0.186	50
Mtns. & Tesserae	7.6	0	32
Craters & No Data	6.8	0	28

Table 1: Airbursts should occur isotopically on Venus, but their observed scars are biased to certain terrains.

We used the airburst scar distribution by terrain from Table 1 to approximate a preservation rate for each geologic unit and ran Monte Carlo simulations of random airbursts. We ran another set of simulations that consider only random points on the Regional Plains and ignore preservation rate. The real airburst scars exceeded the maximum clustering observed in both sets of simulations by >1 standard deviation. Simple terrain-based bias cannot explain the observed clustering.

Ongoing Work: We will account for other factors that may contribute to clustering in our simulations—namely impact chains and, ultimately, resurfacing processes. Our preliminary analyses show that, for any given terrain, airburst scars are overrepresented at high elevation. Meteors could break up and produce chains of airbursts scars, which would increase the degree of observed clustering. Lastly, accounting for modification and/or destruction [7] of airbursts scars (and, in parallel, impact craters) through aeolian erosion and volcanic events will allow us to test global resurfacing models.

We also have plans to simulate meteor airbursts and their interactions with the surface with a shock physics code. We will use these simulations to study the processes that produce the unique morphology of airburst scars. We will also benchmark the scaling between the properties of an impactor and the size of the geologic scar—allowing us to compare impactor production functions to the size distribution of scars.

Conclusion: Venus is the superlative place to study meteor-atmosphere-surface interactions, which produce ~20–30% of the observed impact record. New insights into the formation and destruction of airburst scars will help reveal the resurfacing history of Venus. With three new missions to Venus, now is past time to maximize the science return from Magellan and make predictions for future missions. VERITAS and EnVision will acquire vastly better radar imagery of the airburst scars. Understanding these unique features will help test dueling paradigms for the evolution of Venus writ large.

References: [1] Strom et al. (1994), *JGR*, *99*, 10899–926. [2] Ivanov & Head (2013), *PSS*, *84*, 66–92. [3] Bjonnes et al. (2012), *Icarus*, *217*, 451–61. [4] O'Rourke et al. (2014), *GRL*, *41*. [5] Zahnle (1992), *JGR*, *97*, 10243–55. [6] Wood (2000), *UArizona PhD thesis*. [7] Kelly et al. (2018), *LPSC*, *49*, 2083. [8] Ivanov & Head (2011), *PSS*, *59*, 1559–1600.