CAMPO DEL CIELO STREWN FIELD: MODELING AND COMPARISON WITH OBSERVATIONS.

A. Schmalen[1,2], R. Luther[1,] and N. Artemieva[1,3,4]. [1]Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany. [2]Christian-Albrechts-University, Institute of Geoscience, Kiel, Germany (andrea.schmalen@stu.uni-kiel.de). [3]Planetary Science Institute, Tucson, USA. [4]Institute for Dynamics of Geospheres, Moscow, Russia.

Introduction: Campo del Cielo (CdC) is a 4000-year-old [1, 2] strewn field in the south of the Chaco province, Argentina, which was caused by an impact of IA iron octahedrite [3]. This strewn field has an extremely elongated pattern extending over an area of ~14 km (downrange) by ~3.5 km (lateral). Another interesting characteristic of CdC is that a lot of depressions found within the strewn field are not impact craters but penetration funnels [4] in which intact meteorites could be found including 30-ton-weight fragments. This study presents an attempt to reconstruct the Campo del Cielo impact event, i.e., to estimate the minimal pre-atmospheric mass and velocity of the meteoroid, its fragmentation during the atmospheric entry, and to compare the resulting strewn field with the observed one.

Methods: The process of meteoroids entering atmosphere can be described with an ordinary differential equation system, which combines drag, gravity and ablation with some kinematic equations [5]. In addition, most meteoroids fragment along their trajectory due to dynamic (ram) pressure caused by the atmosphere. To get good approximate solutions, with inexpensive computational power, we use semi-analytical approaches, like the Pancake and Separate Fragment Model in combination with statistics, such as the Size-Frequency-Distribution of fragments, to describe the fragmentation process. We use parameters typical for irons; the single difference is a low ablation coefficient of 0.01 s^2/km^2 typical for large irons (>200 tons [6]). To simulate funnel formation, we use the iSALE-2D shock physics code [7] with initial conditions consistent with the atmospheric entry model.

Results: Description below represents just one possible scenario with a single fragmentation at an altitude of ~20 km whereas plenty of other solutions are possible.

Funnel formation: Preliminary analysis of impact experiments and numerical models [8] show that in the CdC case (iron projectile and loess as a target) funnel formation and projectile survivability is possible at impact velocities below 1 km/s. The iSALE models confirm this estimate: the 1 km/s is probably the upper limit of impact velocity allowing survivability of high strength iron meteoroids impacting into loess. Such low impact velocity requires a specific entry scenario with an extremely shallow entry angle [9].

Atmospheric entry model: To fulfill the condition of the low-velocity landing of largest (~30 tons) funnel-forming fragments, we vary an speed, angle, and fragment mass at an altitude of disruption (~20 km). Our results show that a fragment with mass of 90-100 tons and velocity of 16 km/s reaches the surface with velocity below 1 km/s if the entry angle is in the range of 7-16° to horizon. Several runs for variated speed of meteoroid at disruption in the range of 12-20 km/s show a possible angle range up to 18.5° and a mass range of 60-150 tons for the largest funnel-forming fragments (~30 tons at impact). To reach a match between calculated and observed expand of the strewn field (~14.03 km between impact craters and the most distant small meteorite found in situ), the trajectory angle at the point of disruption should be at least 13° (at a speed of 20 km/s) or up to 15° for a lower speed of 12 km/s. We also estimated the mass and velocity of the four crater-forming fragments using π-scaling-laws. Their summed mass near the surface is at least 3028 tons (at a speed of 18 km/s) and up to 3692 tons (at a speed of 14 km/s). Their corresponding mass at the disruption point is 5348 and 6779 tons, respectively.

Conclusions and Discussion: This scenario suggests that the Campo del Cielo strewn field was formed after an atmospheric entry of a minimal ~9000 tons in mass iron meteoroid (~13 m in diameter) at a shallow entry angle of ~16° and a speed of 14-18 km/s. Crater-forming fragments impacted the surface with a velocity of 4-6.5 km/s at an angle of ~14°; funnel-forming fragments (5-31 tons) and smaller meteorites (3-5 tons) landed with velocities < 1 km/s at various angles up to 45°. We successfully reproduced the length of the CdC strewn field, but its lateral extension is substantially smaller than the observed one. Dependence of funnel's length on fragment mass (and hence, its velocity) requires additional runs.

Acknowledgment: The authors acknowledge the funding from the ESA project P3-NEO-VIII. The authors are grateful to Shawn Wright for the update of CdC field observations.

References: [1] Cassidy W. A. et al. 1965. *Science* 149: 1055–1064. [2] Cassidy W. A. and Renard M. L. 1996. *M&PS* 31:433–448. [3] Liberman R. G. et al. 2002. *M&PS* 37:295–300. [4] Vesconi M. A. et al. 2011. *M&PS* 46:935–949. [5] Artemieva N. A. and Shuvalov V. V. 2001. *JGR* 106:3297–3310. [6] Revelle D. O. and Ceplecha Z. 1994. *A&A* 292:330–336. [7] Wünnemann K. et al. 2006. *Icarus* 180: 514–527. [8] Kadono T. 1999. *PSS* 47: 305–318. [9] Collins G.S. et al. 2017. *M&PS* 52:1542–1560.