NUMERICAL SIMULATION OF NON-BALLISTIC EJECTION PROCESSES AS A FUNCTION OF MATERIAL PROPERTIES. R. Luther[1], K. Wünnemann[1] and N. A. Artemieva[2,3], [1]Museum für Naturkunde Berlin, Leibniz Institute for Research on Evolution and Biodiversity at the Humboldt University Berlin (Invalidenstraße 43, 10115 Berlin, Germany, robert.luther@mfn-berlin.de, [2]Planetary Science Institute, Tucson, [3]Institute for Dynamics of Geospheres, RAS, Russia.

Introduction: The ejection of material is an essential part of the impact cratering processes. The distribution of impactites in the vicinity of impact craters through ballistic transport is fairly well understood. However, deviations from the relatively simple ballistic ejection model are not negligible: the trajectories of small particles (dust, spherules, condensation products) can be affected by the perturbed atmosphere and by the expanding impact plume. The size-frequency distribution of ejected material, the ejection angle and velocity are parameters that depend on the material properties of the target and on the impact scenario. Such effects are difficult to investigate by laboratory experiments because the impact velocities are too small to create an impact plume, material properties affecting the ejection process may be scale-dependend, and atmospheric stratification cannot be reproduced. For a systematic study of ejecta, numerical models are an appropriate tool if they were validated and calibrated against laboratory experiments.

In the framework of the MEMIN (Multidisciplinary Experimental and Numerical Impact Research Network) impact experiments on different geological target materials (e.g. sandstone, marble, tuff) and with various projectile materials (e.g. steel, aluminum, Campo de Cielo iron meteorite) have been carried out at the Fraunhofer Ernst-Mach Institut (EMI). At the two locations of Freiburg and Efringen-Kirchen, the EMI operates light gus guns (SLGG and XLLGG) that are capable of accelerating projectiles with a mass on the order of ~100 mg and ~5 g, respectively, to velocities of up to 5-8 km/s [e.g. 1]. The ambient pressure in the target chamber of the smaller SLGG was set to about 1 mbar, whereas the pressure in the larger chamber of the XLLGG was reduced only to 50 mbar and then increased to 300 mbar by flooding the chamber with N_2. By usage of ejecta catchers and high-speed framing cameras, a detailed analysis of ejection angle, velocity, fragment size, state of damage, and initial ejecta location was possible [2, 3].

The goal of this study is to use observations from the MEMIN experiments focusing on the early stage where a bright flash was observed followed by the ejection of material as constraints for numerical models. In the first step we implement specific tools in our shock physics code iSALE to simulate non-ballistic flight of ejecta following the approach [4-6]. In the second step the models will be compared with observations from the experiments, and in the third step we will use the validated models to investigate the ejecta distribution on natural scale and as a function of different target properties and varying atmospheric conditions (e.g. Moon, Mars, Earth, and Venus) more systamtically..

Methods: In this work we use the iSALE shock physics code [7-9]. The strengths of iSALE are (1) the different available material models including dynamic fracturing and the use of various equations of state, and (2) the porosity compaction model [9]. It has been demonstrated previously that the ejection (ejection velocity and angle) of material is significantly affected by material properties such as porosity, friction, and cohesion [10]. To underline this influence, we show two typical trajectories from our models with no porosity and with 44% porosity (Fig. 1). In most studies so-called tracer particles are used to investigate the distribution of the ejected material. The simplest approach is to record the angle and velocity of tracers when they are ejected from the target and than to compute their parabolic trajectories in a post-processing step. This method has been successfully used to reproduce ballistic ejection in laboratory experiments in sand [10, 11, see also companion abstract by Wünnemann et al., “Insight into crater formation, shock metamorphism and ejecta distribution from laboratory experiments and modeling”]. However, the interaction of ejecta with a perturbed atmosphere or an expanding impact plume cannot be addressed by this method.

We follow the in-code approach by Shuvalov [4], and transform iSALE tracers into representative particles (RP) which are characterized by size, shape, their own velocity, and interact with the surrounding gas phase (atmosphere or vapour). In contrast to the ballistic flight in vacuum it is now important to take the size of ejecta into account. Each RP represents a certain size-class of ejecta. As the size-frequency distribution of ejecta is not well understood we use empirical data from the MEMIN experiments [2, 3]. The main forces exerted on the ejected particles are gravity and drag by a surrounding gaseous medium:

$$F_{drag} = \frac{1}{4} C_D \pi d^2 \rho v^2 + 3\pi d \mu v, \quad (1)$$

where C_D is the drag coefficient, *d* the particle diameter, *ρ* and µ are gas density and viscosity, and *v* is the difference between particle and gas velocity. The first term represents standard high-velocity drag, the second describes Stokes' force.

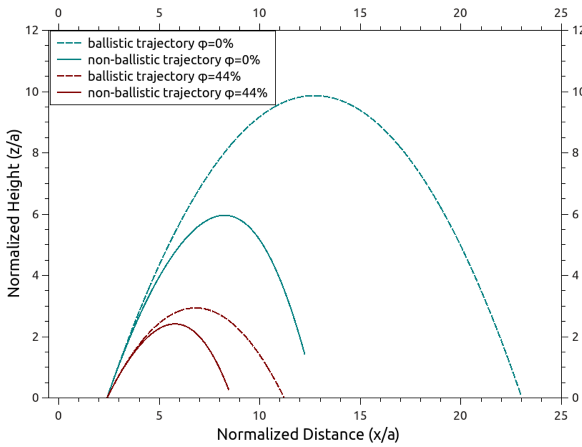

Figure 1: Ballistic and non-ballistic trajectories (dashed and solid line, respectively) for a a typical ejecta particle from a non-porous target (cyan) and for a particle from a target with 44% porosity (red). Both, porosity and atmospheric drag, tend to shorten the distance to deposition.

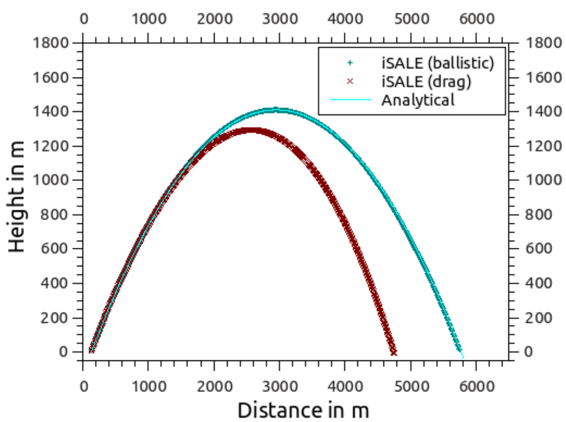

Figure 2: Representative Particle Trajectory. In turquoise it is shown the analytical solution of a ballistic parabola, in cyan the trajectory calculated by the iSALE model and in red the trajectory calculated by the iSALE model including drag.

Results: As the first test of the representative particle approach, we compare the modelled trajectory of particles ejected into vacuum with an analytical solution for a ballistic parabola (Fig 2). Then we introduce atmosphere (described as an perfect gas) in our model. The applied drag is calculated at each time step according to the equation (1). As expected the resulting trajectories differ from the ballistic parabola in vacuum and depend strongly on the projectie size. We assume that ejecta consists of 1-10 cm-radius spherical particles with the drag coefficient of 0.5

Discussion: Our first results of the trajectory of representative particles in vacuum are in accordance with the analytical solution. Deviations between the in-code approach and the ballistic parabola are small (on the order of a few percent depending on model resolution, Fig. 2).

The results of the trajectory in the case of undisturbed atmosphere look reasonable. Also in this case, the trajectory can be described by the analytical solution (Fig. 1). To simulate the behavior of realistic ejecta, we plan to implement the ejecta size distributios as measured by Sommer et al. [2] in the MEMIN experiments and as discussed in detail by Melosh [12] or Artemieva and Ivanov [5]. It's also important to include more realistic atmosphere, which may be disturbed, first, by the flight of the experimenta projectile and the crater excavation, and second, by nearby particles within the ejecta curtain.

Acknowledgements: This project is part of the MEMIN FOR887 funded by the German Research Foundation: DFG-grant # WU 355/6-2.

References: [1] Poelchau M.H. et al. (2013) *Meteorit. & Planet. Sci., 48*, 8-22. [2] Sommer F. et al. (2013) *Meteorit. & Planet. Sci., 48*, 33-49. [3] Buhl E. et al. (2014) *Icarus, 237*, 131-142. [4] Shuvalov V.V. (1999) *Shock Waves 9*, 381-390. [5] Artemieva N.A. and B. Ivanov (2004) *Icarus, 171*, 84-101. [6] Artemieva N.A. et al. (2013) *Meteorit. & Planet. Sci., 48*, 590-627. [7] Amsden A. et al. (1980) *LANL, LA-8095*, 101. [8] Collins G.S. et al. (2004) *Meteorit. & Planet. Sci., 39*, 217-231. [9] Wünnemann K. et al. (2006) *Icarus, 180*, 514-527. [10] Collins G.S. and K. Wünnemann (2007) *Bridging the GAP II*, 8040. [11] Cintala M.J. et al. (1999) *Meteorit. & Planet. Sci., 34*, 605-623. [12] Melosh H.J. (1989*) Impact Cratering: a geologic process* (Oxford: Oxford University Press).