COLLISIONS, GAS FLOW, AND THE FORMATION OF PLANETESIMALS. G. Wurm, O. Krauß, and G. Paraskov, Institute for Planetology, University Münster (Wilhelm-Klemm-Str. 10, D-48149 Münster, Germany, e-mail: gwurm@uni-muenster.de).

Introduction: It is widely believed that planets – at least terrestrial planets – form through collisions of km-sized planetesimals in protoplanetary disks [1]. It is not yet settled though how these planetesimals form. The standard model assumes that they form through collisions of smaller bodies from micron-sized dust particles all the way up to planetesimals. However, as bodies of approximately m-size would emerge from this growth, collision velocities with smaller bodies could reach 50 m/s or more, depending on the model disk [1,2]. So far all experiments show that such a collision on its own will lead to erosion of colliding bodies – not growth. This is a fundamental problem of planetesimal formation.

Collisions and Gas: It has to be considered though that the relative velocities and thus collision velocities are generated by the different coupling of different sized bodies to the gas in a protoplanetary disk. E.g. since the gas is supported by a pressure gradient it rotates slower than Keplerian. For a larger body on a more or less Keplerian orbit this results in a gas flow relative to the body. In the reference frame of this body this gas flow looks like a head wind in which smaller bodies are entrained and can collide with it. Recently, we experimentally showed that this head wind can return fragments (ejecta) from a collision to the eroded larger body after a collision. The slower secondary collisions can then lead to a net growth of the larger body [3,4]. It has been suggested that a limit in size of a growing body might be reached once the transition from free molecular gas flow to continuum gas flow has been made. Gas flow around a *solid* (monolithic) body would then transport ejected particles around. This limit would be approximately a few meters at 1AU distance from a star [2].

Porosity and the Boundary Layer: However, growth of m-sized objects might not necessarily be the limit. Planetesimals and their precursors in protoplanetary disks are very porous. Thus gas flow around such bodies will be accompanied by gas flow through them. We calculate how this gas flow will influence an impact of a small body on a body larger than 1 m in size. On the front side of the larger body (target) with high porosity a thin boundary layer exists (Fig. 1) which is characterized by a gas flow towards the surface. We find that under typical conditions with respect to collisions in protoplanetary disks fragments of a collision will stay inside this boundary layer (Fig. 2). These fragments return to the target by gas drag [5]. Due to the slow collision speeds of these secondary collisions they will stick to the target and add mass [6].

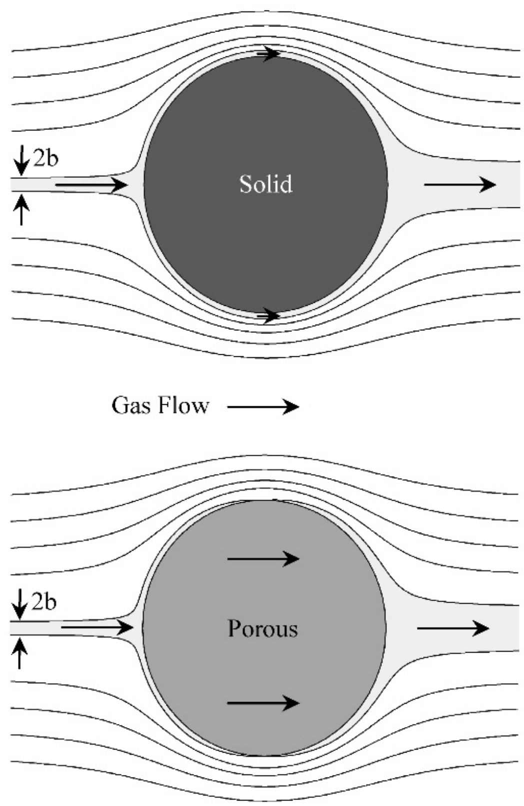

Fig. 1 Gas flow around a porous body will be accompanied by a slow gas flow through the body. A boundary layer of thickness b, in which the gas flow is directed towards the surface, exists on the front side. Particles which are entrained in this gas flow (ejecta) can slowly collide with the body (a second time) and stick. Taken from [5].

A net growth of a larger body occurs. The mechanism might work for all sizes up to planetesimal size (km). Details of the process will depend on the initial collision and the distribution of sizes and velocities of ejected particles as well as the gas flow. To study this we currently carry out impact experiments of dusty projectiles colliding with dusty targets in a low pressure wind channel. An image of impacting dust projectiles into a dust target is shown in Fig. 3. First results imply very low ejecta velocities. Taken all together and especially including the gas flow as substantial component of a collision this supports the idea that planetesimals build up in collisions of smaller bodies [5].

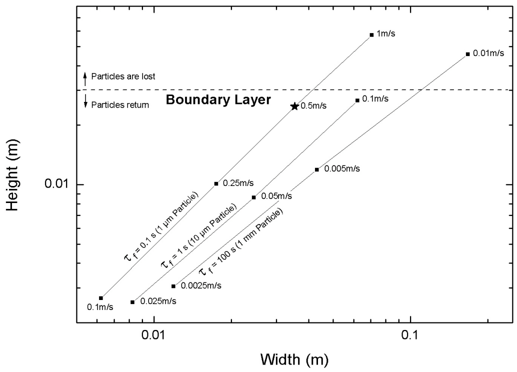

Fig. 2 Width and maximum heights of particle trajectories after a collision of a dusty projectile with a dusty porous body for different gas-grain friction times of the ejected particles and different ejecta velocities in a typical protoplanetary disk. For details we refer to [5]. A data point which we regard as typical is marked by the star. Being within the boundary layer typical fragments would return to the target, stick there, and add mass.

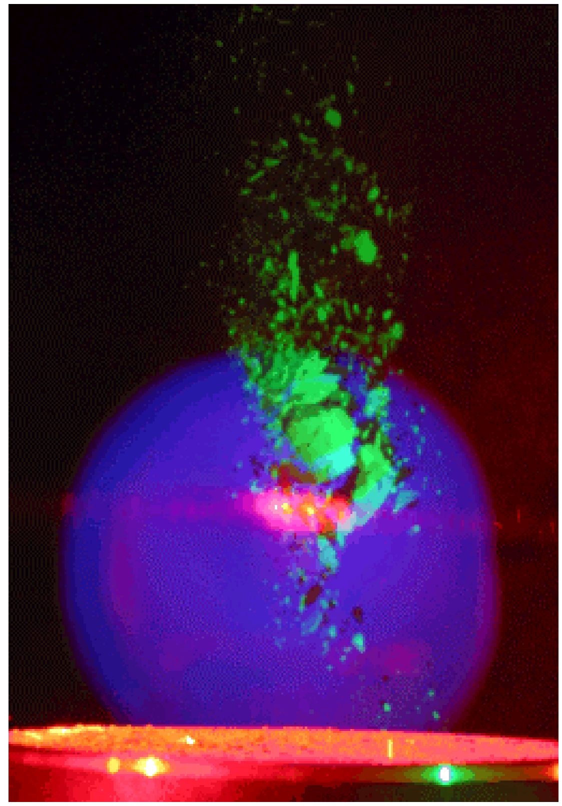

Fig. 3 Image of mm-sized projectile(s) consisting of micron-sized dust before impact into a porous dust target at ~25 m/s (approximately 5cm visible). While a crater is formed, only few ejected particles are observed and most of the mass of the projectile is added to the target. On average this implies very low velocities for any ejected particle. Details will be presented on the conference.

Acknowledgement: This work is supported by the Deutsche Forschungsgemeinschaft.

References: [1] Weidenschilling S. J. and Cuzzi J. N. (1993) *PP III*, 1031–1060. [2] Sekiya M. and Takeda H. (2003) *Earth Planets Space*, *55*, 263–269. [3] Wurm G., Blum J., and Colwell J. E. (2001) *ICARUS*, *151*, 318–321. [4] Wurm G., Blum J., and Colwell J. E. (2001) *Phys. Rev. E*, *64*, 046301 1–9. [5] Wurm G., Paraskov G., and Krauß O. (2004) *ApJ*, (in press). [6] Poppe T., Blum J., and Henning Th. (2000) *ApJ*, *533*, 454–471.