PIEZO DUST DETECTOR (PDD) - A MODULAR MINIATURIZED IN-SITU MEASUREMENT INSTRUMENT FOR DUST RESEARCH. A. Wolf[1,2], R. Laufer[1,2], G. Lightsey[3], G. Herdrich[2,1], R. Srama[1,2,4], H.-P. Röser[2], T.W. Hyde[1], [1]CASPER (Center for Astrophysics, Space Physics and Engineering Research), One Bear Place 97310, Baylor University, Waco, TX 76798, [2]Institute of Space Systems (IRS), Universitaet Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany, [3]University of Texas at Austin, 1 University Station, C0600, Austin, TX 78712, [4]Dust Accelerator Laboratory, Max-Planck-Institute, Heidelberg, Germany (Rene_Laufer@baylor.edu; Truell_Hyde@baylor.edu)

Introduction: Hazard and System Degradation due to the impacts of micrometeoroids, Space Debris and cosmic dust are a major concern for satellite and human spacecraft missions in Earth orbit as well as for robotic and human exploration missions to comets, asteroids, planets and moons. Therefore NASA has declared Space Debris Hazard Mitigation as one of their Space Technology Grand Challenges. This topic is also specified in the Technology Areas of the Draft Human Exploration Destination Systems Roadmap.
Depending on the orbital altitude and inclination the Meteoroid And Space debris Terrestrial Environment Reference model (MASTER 2005) shows that the number of impacts in Low Earth orbit (LEO) ranges from 5000-9000 per m² per year [1]. Taking these results and evaluations on returned surface parts of the Hubble Space Telescope or the Space Shuttle into account it is obvious that the number of impacts on a satellite or spacecraft can easily exceed the thousands. According to the MASTER 2005 model, the mass of the majority of the particles in Earth orbit is about $1 * 10^{-12}$ kg which comes up to a particle size in the range of 1 - 10 µm.

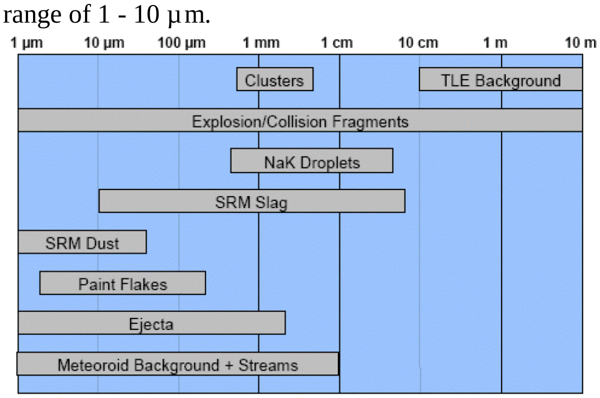

Fig.1 Dust and debris sources considered in the MASTER 2005 model.[2]

As cosmic dust particles transport information over space and time, general information about their origin, evolution and processing will help to understand the formation of solar systems and the origin of life. Since the identification of cosmic dust by the detector onboard the Ulysses spacecraft about 20 years ago, several missions like Stardust, Rosetta, Cassini and Deep Impact gathered information which increased the knowledge of dust generation, evolution and destruction. One of the first dust instruments using piezo based detectors was on board the Giotto spacecraft as part of the Dust Impact Detection System (DIDSY), designed to explore Halley's comet [3].

Current debris models show huge deficits in modeling debris of very small size due to the lack of in-situ data, especially for sub millimeter particles [4]. Data gathered for such small particles would increase the quality of current debris models significantly, which is a prerequisite for improved debris mitigation and removal monitoring.

Additionally, the small size and mass, low power consumption, complexity and cost of the piezo based instrument described below would allow it to be flown on a large number of space-borne platforms.

Piezo Dust Detector: The Piezo Dust Detector described below will be developed by the Center for Astrophysics, Space Physics and Engineering Research (CASPER) of Baylor University in collaboration with the Cosmic Dust Group at the Institute of Space Systems of the University of Stuttgart and the Dust Accelerator Laboratory at the Max-Planck-Institute, Heidelberg.

The design of the Piezo Dust Detector provides the opportunity to be flown on a huge variety of spacecrafts and exploration missions to planets, moons, asteroids and comets as well as in Earth orbit.

The PDD will be a miniaturized, modular in-situ dust and debris measurement instrument based on piezo sensor element technology. The modular design provides the opportunity for a simple addition of detector units to increase the sensor surface or measure impacts on multiple spacecraft surfaces. By using coated piezo sensor elements for the direct detection of particle impacts, both complexity as well as cost of the proposed instrument will be reduced. The concept of the first flight model, which was selected as a potential payload for the ARMADILLO nano satellite, consists of a main detector unit of 9 piezo elements with a total detector surface of approx. 2600 mm², an ion grid in front of the piezo elements, a screening grid in front of the ion grid which provides electromagnetic screening, and associated detector electronics. In addition there will be a secondary detector unit on an opposite or perpendicular surface of the satellite consisting of a single piezo sensor element without grids. As the main detector unit will point in the direction of flight, the secondary detector unit enables the collection of data of impacting particles from e.g. deep space, depending on the selected surface.

The detector will have a mass of less than 500g and a size of about 80 mm X 80 mm X 40 mm which is less than half a cubesat unit. The power consumption during operation mode will be limited to a maximum of 3 W. During operation mode the instrument will create about 150 kByte data per day which is stored within the memory of detector control unit before being downloaded to the ground station.

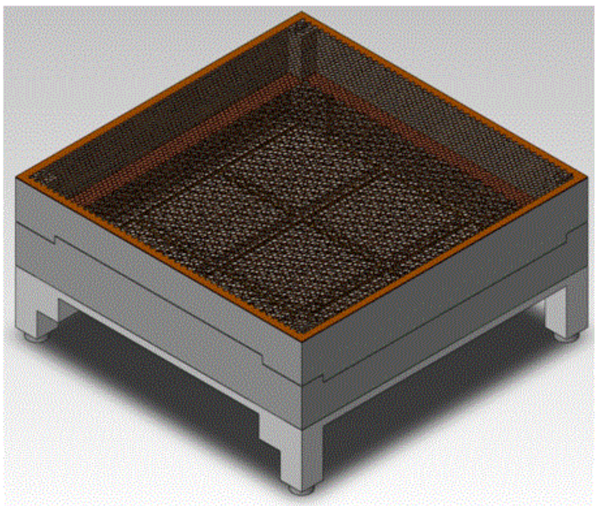

Fig.2 Piezo Dust Detector: Main detector unit with 9 piezo sensor elements and 2 grids.

The signal which is used to detect an impact on one of the piezo sensor element depends on the velocity and the mass of the impacting particle. The sensivity threshold which defines the smallest particle mass for which an impact can be reliably identified, is a function of the impact velocity. In order to detect as many impacts as possible a wide dynamic signal range is essential.

The detector will provide physical parameters of impacting dust and debris particles such as velocity, mass and impact energy. The size of detectable particles will be in the range of 1 µm to 1 mm at a velocity of up to 10 km/s. The maximum measureable impact energy will be approx. 1 J as impacts of higher energy will proabably destroy the piezo elements. Future tests with the Light Gas Gun at the CASPER laboratory will determine the upper limit of the impact energy the PDD is capable to withstand.

Due to a disproportional increase in complexity, the instrument will not provide information about the direction of the impacting particles nor their chemical composition. Nevertheless the difference in orbital velocity will provide a mechanism for distinguishing cosmic dust from orbital debris as cosmic dust has a larger orbital velocity in comparison to orbital debris.

Potential Applications: An instrument such as the Piezo Dust Detector provides the ability to perform consistent dust and debris monitoring during active space missions, whether in Earth Orbit or on planetary, lunar or deep space exploration missions. Due to its low mass, low power consumption, low data rate and small size, the PDD can be flown on any spacecraft or satellite.

The data gathered by the Piezo Dust Detector would also help to increase the quality of current debris models at a large scale, which is essential for the development of a successful debris mitigation and removal monitoring system.

Outlook: The Piezo Dust Detector has been selected as a potential payload for the ARMADILLO (Attitude Related Maneuvers And Debris Instrument in Low Orbit) mission. ARMADILLO is a 3-unit cubesat mission developed by the Satellite Design Lab (SDL) of the University of Texas at Austin. This project will participate in the University Nanosatellite Program UNP-7 with a possible launch opportunity not earlier than 2013.

The first test campaign at the Light Gas Gun at CASPER and the Dust Accelerator of the University of Colorado at Boulder is scheduled for summer 2012.

The first flight test of the PDD is planned to be in fall 2012 as a RockSat-X payload in collaboration with Virginia Tech which will be launched from Wallops Island. Although the flight duration of approx. 20 minutes is not long enough to detect any particle impacts, this test will provide a space qualification for the Piezo Dust Detector.

References: [1] Bauernfeind R. (2007) Study research project. [2] MASTER 2005 User Manual (2005). [3] Grün E., Gustafson B. Å. S., Dermott S. F., Fechtig H. (2001) Interplanetary Dust, 406. [4] Sdunnus, H. et al. (2004) Comparison of debris flux models. Advances in Space Research, 34(5), 1000–1005.