Longitudinal and Lateral Induced Shear Flow in a Complex Plasma as an Astrophysical Analog.
P. J. Adamson[1], C. Carmichael[1], J. C. Reyes[1], V. Nosenko[2], and T.W. Hyde[1], [1]Center for Astrophysics, Space Physics, and Engineering Research (CASPER)
One Bear, Place 97283, Waco, Texas, 76798-7283 USA (parker_adamson1@baylor.edu, truell_hyde@baylor.edu), [2]Max Planck Institute for Extraterrestrial Physics, Garching, Germany.

Introduction: In this research, we present a study on the manner in which induced longitudinal (axial) and lateral (radial) shear flows differ experimentally when stimulated in a three-dimensional (3D) complex (dusty) plasma produced in the PlasmaKristal-4 (PK4-BU) at Baylor University.

In this case, a shear flow is established via radiation pressure from a collimated infrared laser (i.e., a manipulation laser) incident upon a suspended cloud of melamine formaldehyde (MF) spheres held in a DC plasma.

A proper understanding of the shearing effect created within this complex plasma [1-5] is an important first step to exploration of the complicated shearing dynamics present in the rings of Saturn [6] as well as our understanding of the dynamics of other astrophysical systems such as cometary tails [7], protoplanetary shockwaves [8] and lunar dust swirls [9].

In particular, this study is helping clarify the manner in which shear flow damping varies within the broader context of relative direction with respect to cloud structure and other internal flows. Both the experimental technique and initial data analysis will be discussed along with an examination of how the experimental parameters can be modified in order to study the directional dependance of shear flow forces in microgravity conditions using the PlasmaKristal-4 (PK4) aboard the ISS.

At a fundamental level dusty plasma shear flows produced on earth and in orbit have been used to examine shear viscosity [1-5], crystal melting [1,3], the system coupling parameter [1,2] critical shear stress [4], grain clustering [3,4], non-newtonian behavior as observed in a dusty plasma liquid [4], and atomistic behavior of liquids and colloids [1]. Shear melting for 2-D systems has also been shown to be anisotropic [3]; however, work in the PK4 and PK4-BU to date has primarily examined shear flows longitudinally aligned with the tube [5]. Thus, the natural extension of this work is to examine both the longitudinal and transverse shear flow in the PK4-BU in order to determine possible anisotropic behavior.

Experiment: The PK4-BU which consists of a pi shaped cylindrical quartz glass vacuum tube in which dusty plasma may be created and viewed is shown in figure 1. The dust cloud is formed by dispensing micron-sized dust particles into a capacitively coupled polarity switching (500 Hz) DC plasma. By adjusting the flow rate of the gas and the duty cycle of the current supplied (defined as the relative percentage of time spent in each polarity) the dust cloud can be trapped at varying positions along the main tube of the PK4-BU. Using the collimated manipulation laser at high power (>5 W) a shear flow within the complex plasma cloud can be induced for examination.

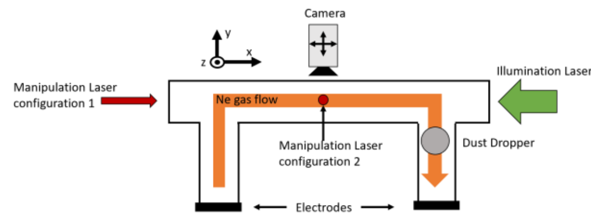

Figure 1: Schematic diagram of the PK4-BU.

All primary data was collected using two high speed cameras, a Single Photron Mini 5247 and a Basler 6033, which allows the motion of the MF particle cloud as illuminated by a 532 nm laser to be recorded in detail. A 532 nm band gap filter was installed on both cameras to eliminate background light from the plasma bulk and the radiation produced by the 808 nm manipulation laser.

A primary benefit of using the PK4-BU is the ability to collect data from more than one camera angle (i.e., the cameras may be positioned in both the vertical and horizontal directions) while employing significantly faster frame rates than possible for the PK4 on the International Space Station (ISS).

Having multiple viewing angles helps us better understand the 3-D flow of the dust cloud – one relevant example is the vortical motion observed encompassing the entire cloud in the horizontal view, but not from the vertical view.

This may only be observed at higher frame rates since these are essential to reducing the 'streaking' of the dust particles shown in Figure 2. As can be seen, this streaking effect creates numerous difficulties in trying to quantitatively analyze the data. Streaking particularly affects the ability to perform particle tracking with the majority of particles unoberservable after one or two frames when a frame rate of 75 FPS or slower is used.

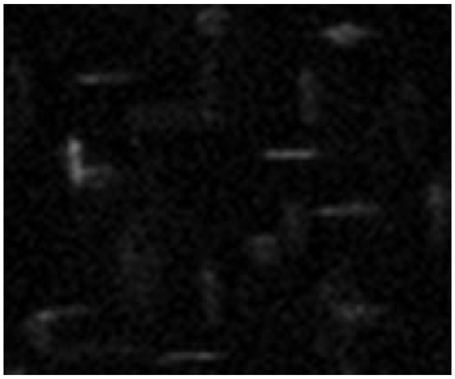

Figure 2: Sample area of a single frame from the Basler 6033 operating at 75 FPS.

Once properly analyzed, this data will enable us to study the interparticle forces that drive shear flows from an atomistic level, and determine how far into the body perturbations due to these shear flows propagate. This is essential for understanding force damping in models of various astrophysical systems. This data may also provide a better understanding of shear flows in dynamic 3D systems in both gravity and microgravity and new experimental procedures on how best to delve deeper into the shearing phenomena observed in dusty plasma systems in microgravity using the PK4 aboard the ISS.

Acknowledgments: This material is based upon work supported by the NSF under Grants No. 1740203, 1707215 & 2008493, NASA under Contracts No. EW20_2-0053, EW-2962-LDRM, NASA / JPL 1571701, JPL 1647194 and the DOE under Grant No. DOE DE-S0021334.

References: [1] Nosenko V. and Goree J.(2004) Phys Rev Lett 93, 155004. [2] Gavrikov A. et al. (2005) Phys. Lett. A 336, 378. [3] Nosenko V. et al.(2013) Phys Rev E 87, 043115. [4] Vorona N. A. et al. (2007) J Exp Theor Phys+ 105, 824. [5] Nosenko V. et al. (2020) Phys Rev Res 2, 033404. [6] M.K. Dougherty, Schmidt J. et al. (2009), Saturn from Cassini-Huygens Ch 14. [7] Price O. et al. (2019) Icarus 319, 540-557. [8] Boss A. P. and Durisen R. H. (2005) Chondrites and the Protoplanetary Disk ASP Conference Series, Vol. 341. [9] Garrick-Bethell I. et al. (2011) Icarus 212, 480-492.