

Center for Astrophysics, Space Physics and Engineering Research  
2010 Baylor University RET Program

Elusive Particle Cloud Velocities  
A Research Adventure to Remember  
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**Abstract-- My experience in the CASPER Research Experience for Teachers Program has been both informational and eye-opening. The lab is like a close-knit community of researchers, not just researchers, but people that are very diverse and yet driven to find answers. They all work together to solve problems. Although these people pursue their own individual research problems, they are always willing to extend a hand to help others with theirs. In this paper I will describe some of the adventures and discoveries that occurred in the lab, especially using a GEC cell to observe dust particles only 8.9 microns in size and to determine their change in displacement in Nd:YAG laser light**

### **The Friendly Researchers**

The adventure begins at the Hypervelocity Impacts and Dusty Plasma Lab (HIDPL) where I worked this summer and encountered some very helpful people. Jorge was my mentor (see image 1) and frequently helped me when I couldn't get Matlab to run; usually I had typed in the wrong code. His patience seemed unending. Jai was the ImageJ expert and I knew I could always turn to him when I was flummoxed (see image 2). I could always turn to Angela if I wanted to know something about the cell.



Image 1: Jorge, Gary, Karen

She is a graduate student and is very close to getting her master's degree in Physics. Angela was very knowledgeable about how everything worked in the cell (see image 3).



Image 2: Steve and Jai



Image 3: Angela operating Cell 1

Only a few of the researchers are mentioned here. All of them made me feel right at home and every single one of them helped me in some way. The HIDPL is definitely a community of focused learners!

### **The Lunch Bunch Seminars**

Every Wednesday we had the Lunch Bunch Seminars. We had a different speaker each week to inform us of their research or talk about other explorations. I will mention only a couple here. Dr. Rene Laufer of Baylor Space Science Lab presented the

first talk, Doing Space. He talked about the difficulty of getting just a small satellite into space; it all starts with many good ideas. Dr. Laufer said that modern cell phones have most of the components needed for a small satellite. He informed us that Baylor has formed a partnership with Stuggart University in Germany to build a small satellite and launch it into lunar orbit. Of course proposals, funding and hardware testing are all part of the process. The LUNAR MISSION BW1 is an academic small lunar orbiting satellite under development now. This lunar exploration and technology demonstration mission will perform both in-situ and remote sensing experiments with a planned scientific focus around particle, dust and meteoroid research

As part of a collaborative agreement between Baylor University and Stuttgart University, the Center for Astrophysics, Space Physics & Engineering Research (CASPER) will contribute an instrument in the field of plasma and/or dust detector research to the scientific payload. The spacecraft will be propelled by a solar-electric propulsion system. A 1 kw ammonia-driven thermal arcjet will provide up to 100 mN of thrust during the ascent through the Van-Allen belt. A cluster of pulsed magneto-plasma-dynamical thrusters providing 1.5 mN each and using solid PTFE (Polytetrafluorethylene a.k.a. Teflon) will act as the main propulsion system during cruise phase [1].

Dr. Victor Land gave a very nice presentation about The Physics of Golf. He talked mostly about the interaction of the golf ball and the club. The interaction between the club head and the ball will determine how far the ball will go and in which direction. There is a relationship between the speed of the club head and the initial velocity of the ball. This relationship depends on the coefficient of restitution of the ball, which varies between different types of balls. When the ball is struck by the club, it is deformed and flattened by the force of impact (balls with harder cores deform less than softer balls). In general, a harder ball will travel further than a softer ball because it deforms less and will efficiently transfer more energy from club to ball. During the impact between the ball and club head, kinetic energy is transferred and stored as the ball tries to regain its original shape. This coefficient of restitution is quite similar to the restoring force. To obtain maximum distance in the drive, a ball must be selected that maximizes restitution for the club speed. If the chosen ball is too soft for the club speed, too much energy will be spent deforming the ball and not enough energy will be stored in the ball. Similarly, if the ball is too hard for the club speed, then the ball will not deform enough, and again, will not transfer adequate energy. This is why it is important to choose a ball that matches the club speed. Figure 1 shows a graph relating initial velocity of the ball with club speed [2]:

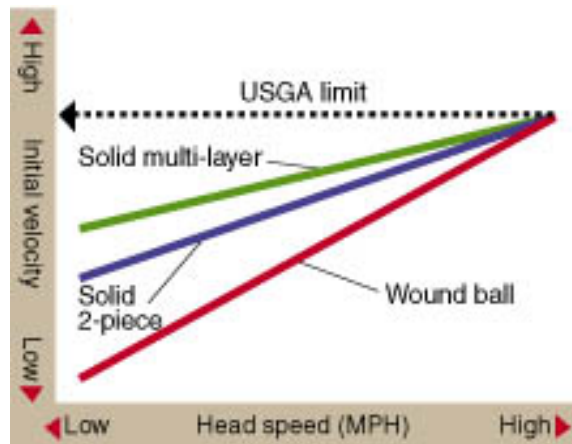


Figure 1: Initial Ball Velocity vs. Club Speed

## Java Particle Image Velocimetry (JPIV)

One of the things I wanted to take back to my students was the thrill of doing research themselves. I think that JPIV may be the answer to that wish because it is free (see the next section). After looking through thousands of frames of dust particles I have plenty of data that they can have access to. But I may be getting ahead of myself so let me tell you about JPIV.

The term “particle image velocimetry” first appeared in the literature about 25 years ago. Java particle image velocimetry appeared about 5 years ago, so it is relatively new [3]. So, JPIV is an optical method of fluid visualization. It is used to obtain instantaneous velocity measurements and related properties in fluids. The fluid is seeded with tracer particles which, for the purposes of PIV, are generally assumed to faithfully follow the flow dynamics. It is the motion of these seeding particles that is used to calculate velocity information of the flow being studied [4]. Images 4 and 5 on the next page show an example of tracer particles (leaves and bubbles) in a stream and the resultant velocity vectors are shown in figure 3. If you look closely you will see a slight difference in the location of objects in the two photos. The displacement of the particles from one frame to the next is computed by the JPIV program, hence when the time between frames is known the velocity can be calculated.

In the work done at HIDPL the entire image is divided into a grid of (usually overlapping) interrogation spots, and the particle images in each spot are interrogated to obtain the mean displacement of the particles within each interrogation cell. JPIV can be used to trace dust particles in a plasma environment. Image 7 shows the resultant velocity vectors or two successive frames taken from the vertical video camera on cell 1. As you can see the maximum velocity computed by JPIV is 9 pixels/second. I would like to find a way to convert the velocity into m/s. I think it would make more sense to my students. I plan on burning a CD of CASPER dust particle data so that each student will have the data. I will give these out during orientation at the beginning of school. I think my students will learn much about the ups and downs of research work.





Image 4: Frame 1 of stream dynamics

Image 5: Frame 2 of stream dynamics

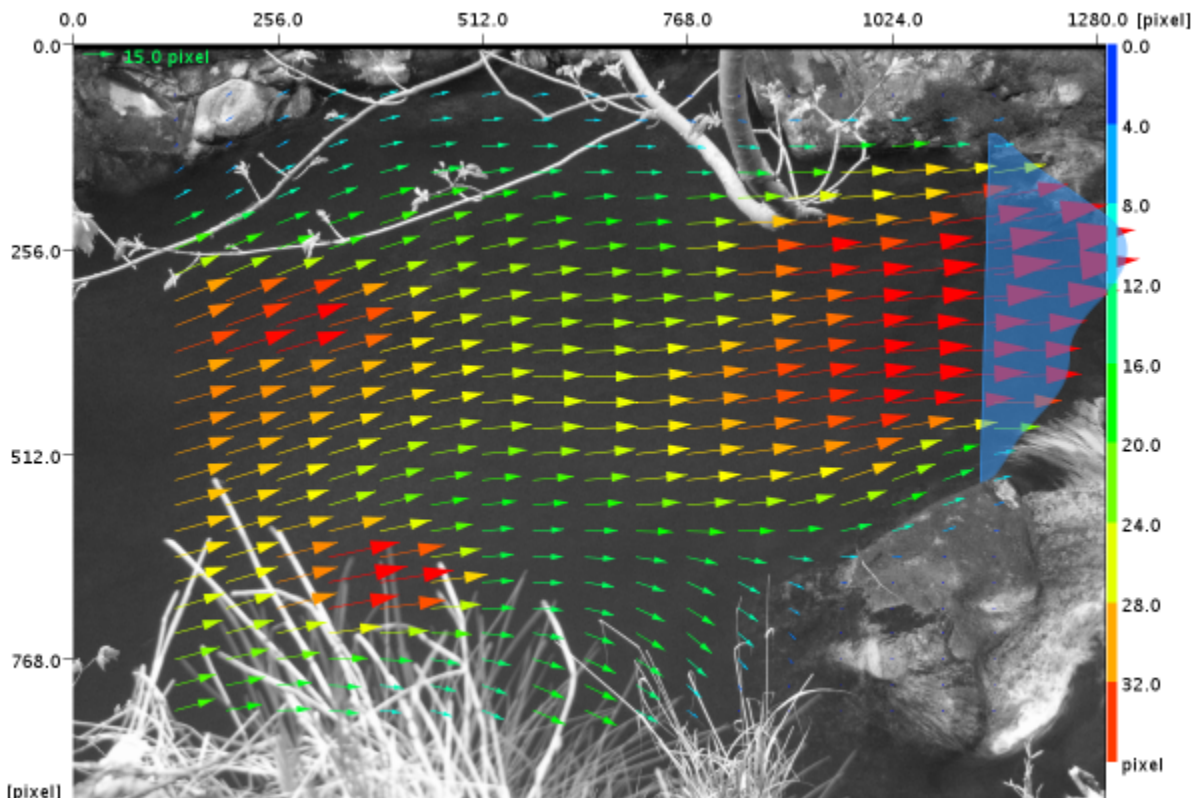


Image 6: JPIV visualization of velocity vectors on the stream surface (images from JPIV website) <http://www.jpiv.vennemann-online.de/introduction.html>

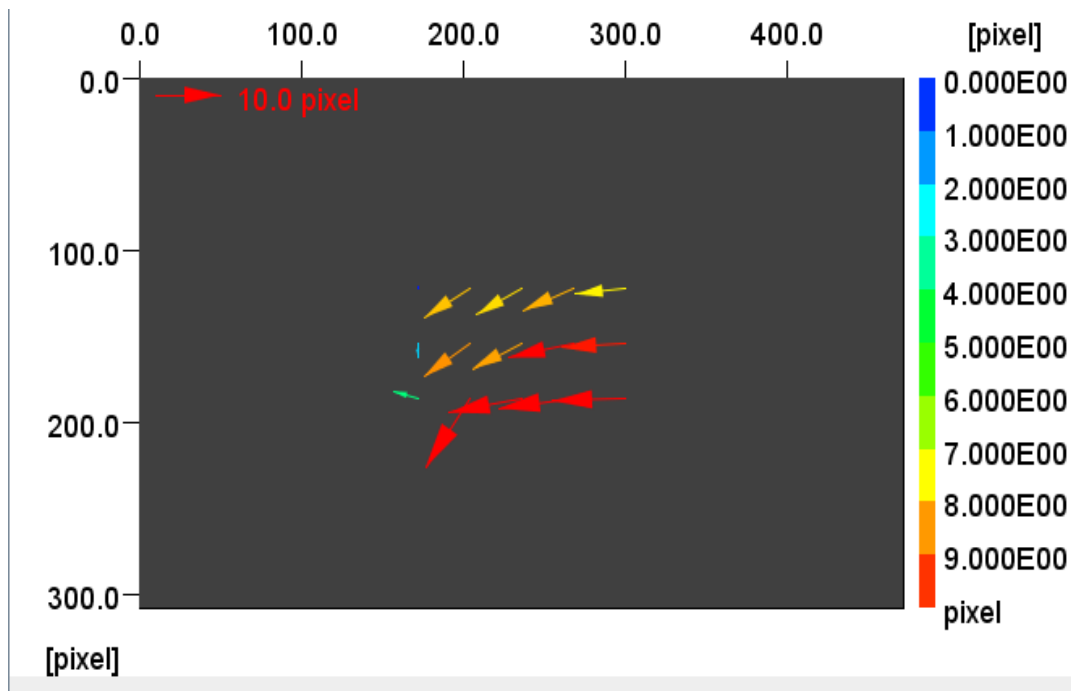


Figure 3: Velocity vectors of dust particles in a plasma environment

### Directions for Downloading JPIV

This program can be downloaded at <http://www.jpiv.vennemann-online.de/>. Your computer will also need to have Java Runtime Environment which can be downloaded here ([Sun's free of charge JRE](#)) if you don't have it. Although the executable file can be downloaded and run manually, I have found that the program seems to work just as well by running the web version. However there are several files that need to be downloaded from the web site above in order for the program to run correctly. Click on the download area at the upper left of the page and download the files found here: [Java Advanced Imaging \(JAI\)](#). On the left side of the page download the file found in the box labeled lib, a zip-archive (7.7 MB). Extract the files to your hard drive and tell JPIV where to find the unpacked directory. Restart JPIV to list the scripts of the jpilib/jsc directory in the Scripts drop-down menu.

### Cell 1 and Elusive Dust Particle Cloud Velocities

All of the observations of dust particles were done in Gaseous Electronic Conference (GEC) cell 1. The objective of this project was to determine the velocity of melamine formaldehyde gold coated particles of 8.9 microns in diameter in a plasma environment. A charged environment is created within the cell where temperature and pressure can be controlled. In this experiment micrometer sized dust particles are introduced from the top of the cell. During their fall toward the lower electrode, they collect ions and electrons from the plasma and charge up. Due to the high electron mobility, this charge is negative and the dust particles are trapped in the electric field above the bottom electrode. The dust particles can be seen by illumination with a diode

laser of 640 nm and 0.87 mW as shown in image 8 below. Very little if any movement occurred. Rapid movement of the particles occurred when a variable watt (up to 5 W) green Neodymium-Yttrium Aluminum Garnet (Nd:YAG) laser was used to illuminate the dust particles as shown in image 9. The Nd:YAG laser was turned on and off periodically to note its effect on particle movement. The particles consistently moved more rapidly in the green coherent light. The forces involved in this “pushing” of the particles seemed to be electrostatic in nature [5]. Particles illuminated by the red laser light did not move significantly in the horizontal direction. Images 10 and 11 compare the movements of the particles in different illuminations.

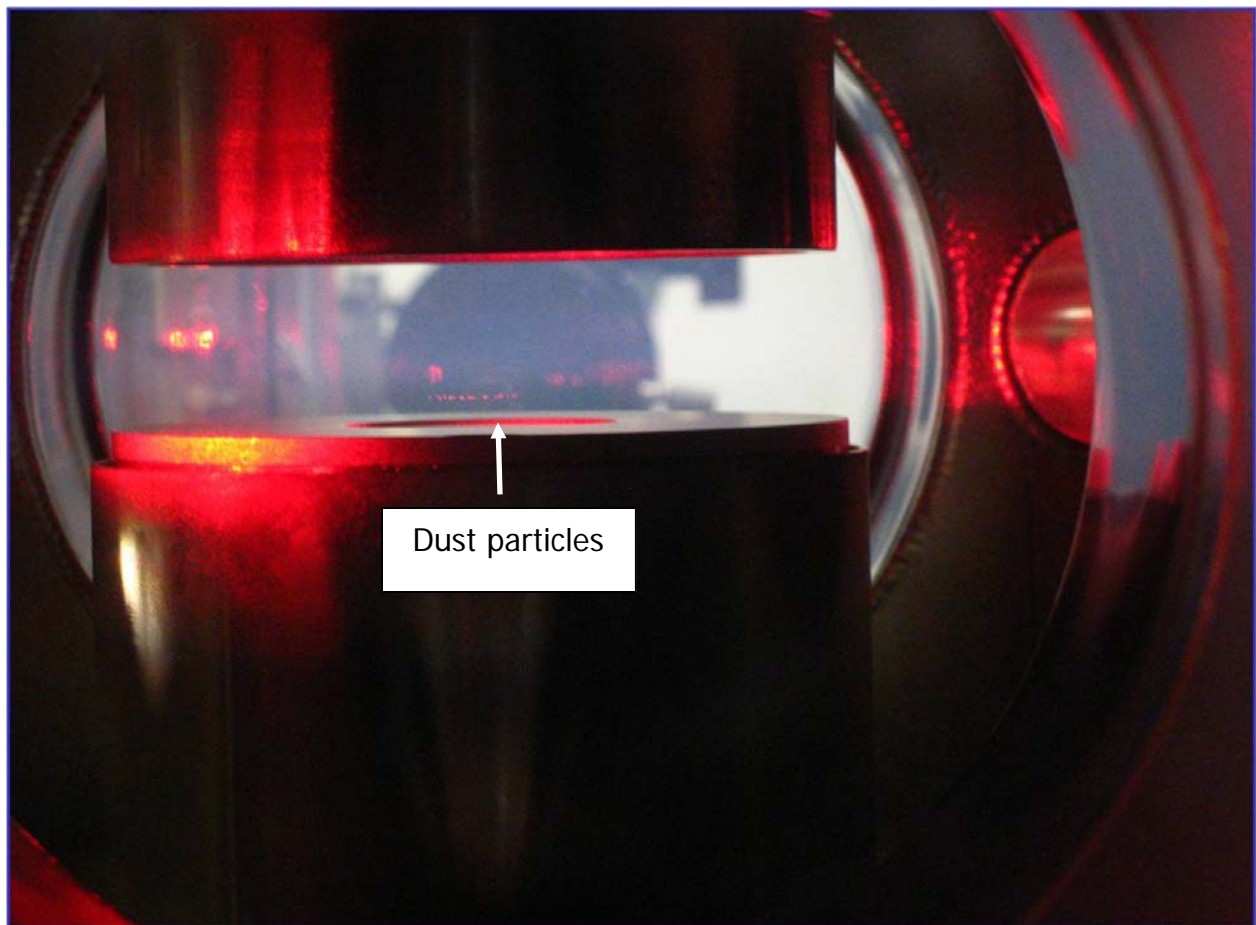


Image 8: Dust particles illuminated by the diode laser



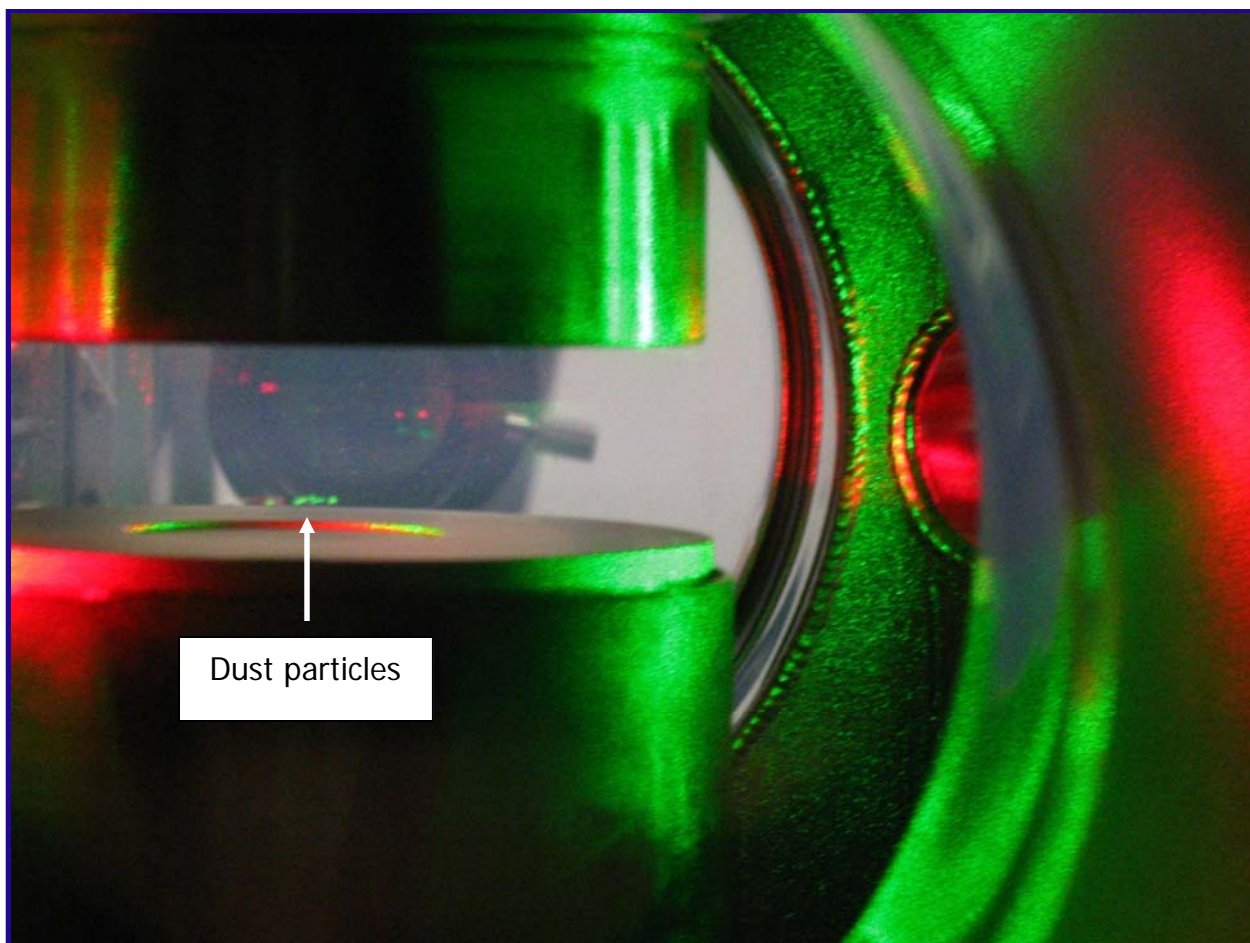


Image 9: Dust particles illuminated by diode laser + Nd:YAG laser

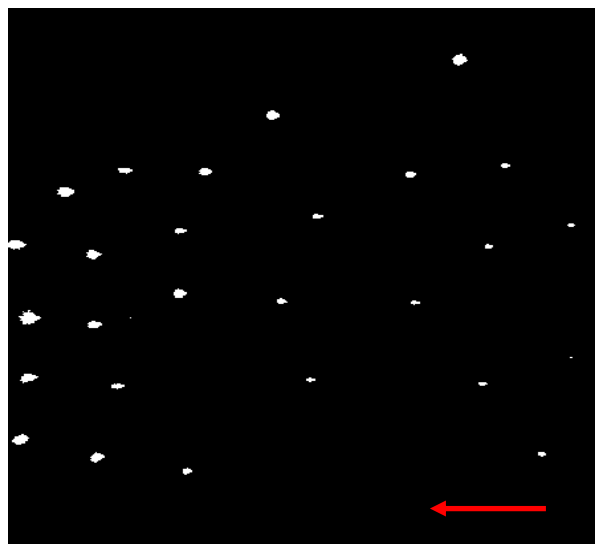


Image 10: Nd:YAG laser at 532 nm



Image 11: Diode laser at 640 nm



## Matlab PIV

To find the elusive dust particle velocities Matlab Particle Image Velocimetry (PIV) was used. The main goal was to create a program that would clean the images taken by the top view video camera mounted on the GEC cell (see image 10 and image 11). Generally 2000 image frames were taken from the camera. Also a program was needed that could track the particles in each frame and compute a velocity of the particle cloud. Untold hours were spent creating the needed code for the programs. It is hoped that this will aid future researchers as they embark upon a search for particle velocities. It generally took about 2-3 hours to clean the images and then another 5-6 hours to get velocity vectors for the particles. Numbers of particles varied from about 10 to 600.

After writing and changing codes over and over again we finally saw some results. Several informative graphs were created showing movement of the particles frame by frame. The particles changed position when the Nd:YAG laser was used to illuminate the particles. Figure 4 shows a stack of 600 frames and the long vertical rods illustrate the particle movement. The initial position of the particle starts at the bottom of the stack. A vector plot of the particles' change in position was also created and is shown in figure 5. Another plot was created that does not have positions or magnitudes but seems to show movement of the particle very nicely (figure 6). It seems to give more detail about particle movement than the plot in image 5.

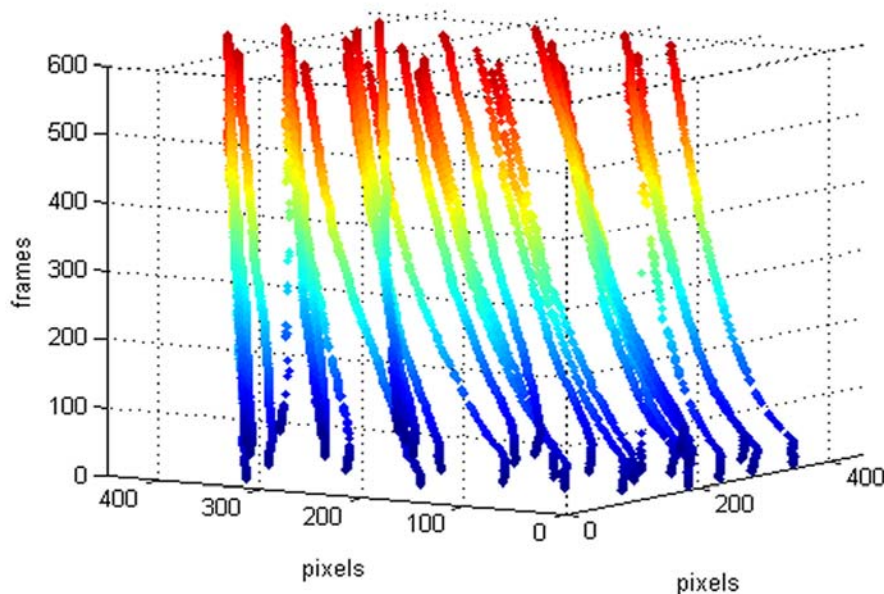


Figure 4: Stacks of frames showing particle movement over time

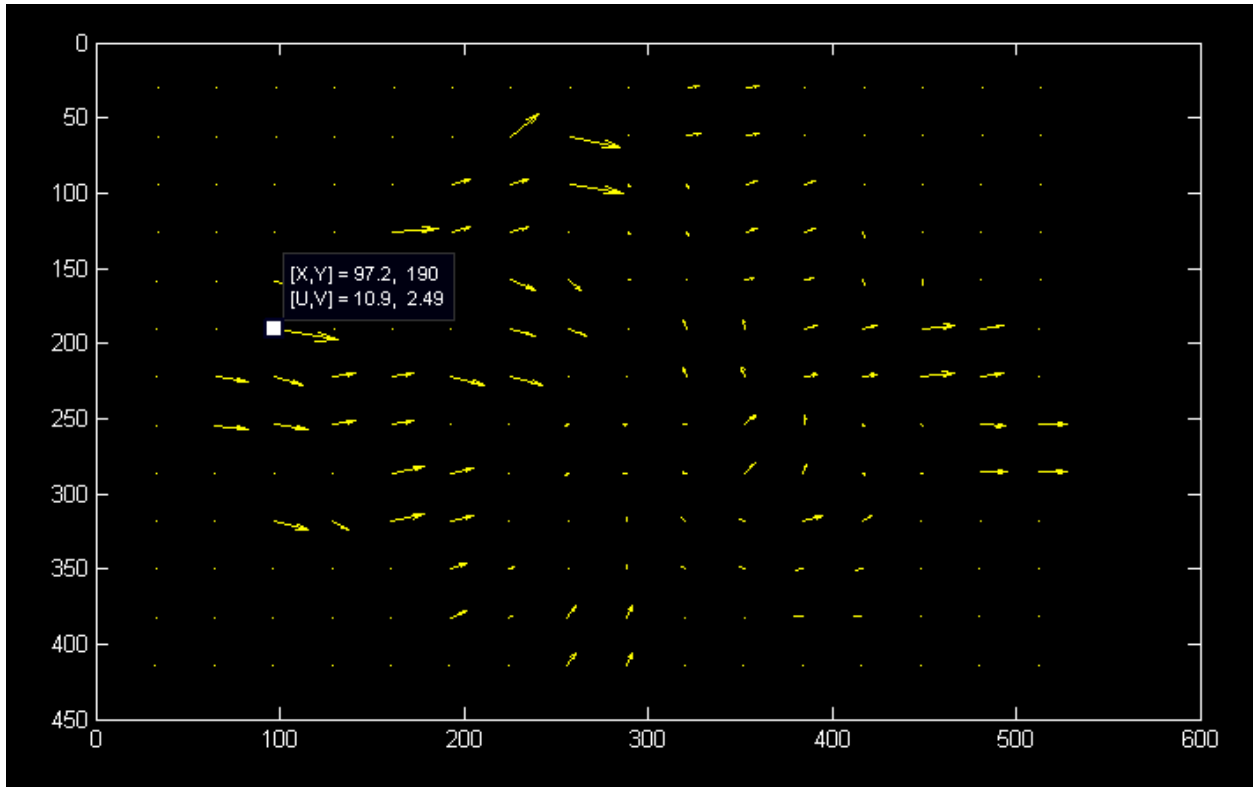


Figure 5: Vector plot of particle movement and velocity; the horizontal velocity is  $U=10.9$  pixels/s and the vertical velocity is  $V=2.49$  pixels/s.

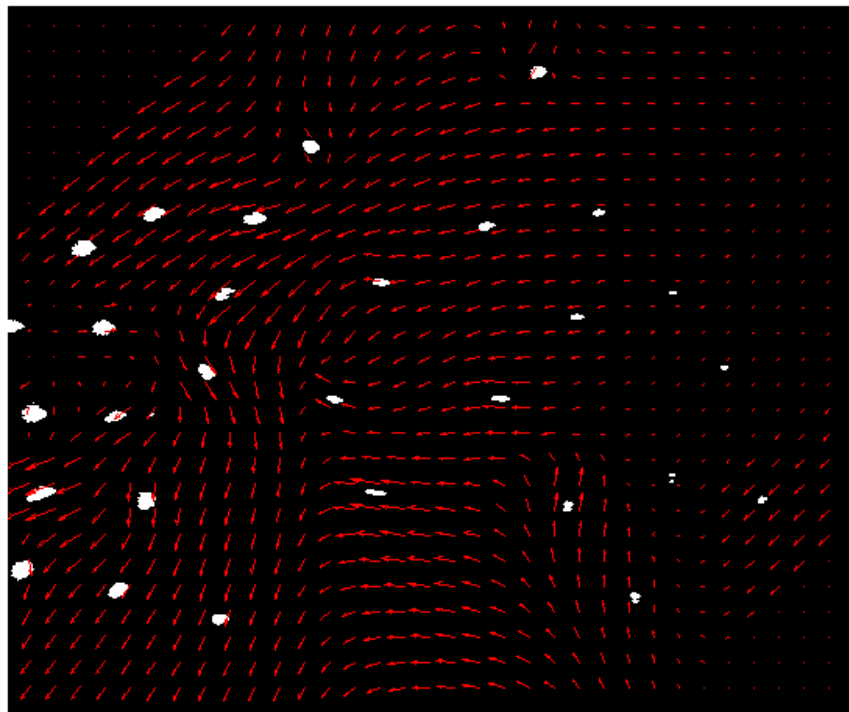


Figure 6: Vector field showing movement of particle between frames

A graph of mean and median particle velocities of 8.9 micron malemine formaldehyde was constructed and is shown in figure 7. A similar graph of 8.9 micron gold coated particles with a malemine formaldehyde (MF) core was also constructed as shown in figure 8. It is not surprising to find the MF velocities were higher than the gold coated particle velocities since their mass would tend to be greater than the MF particles. It appears that the original goal of this research has been reached.

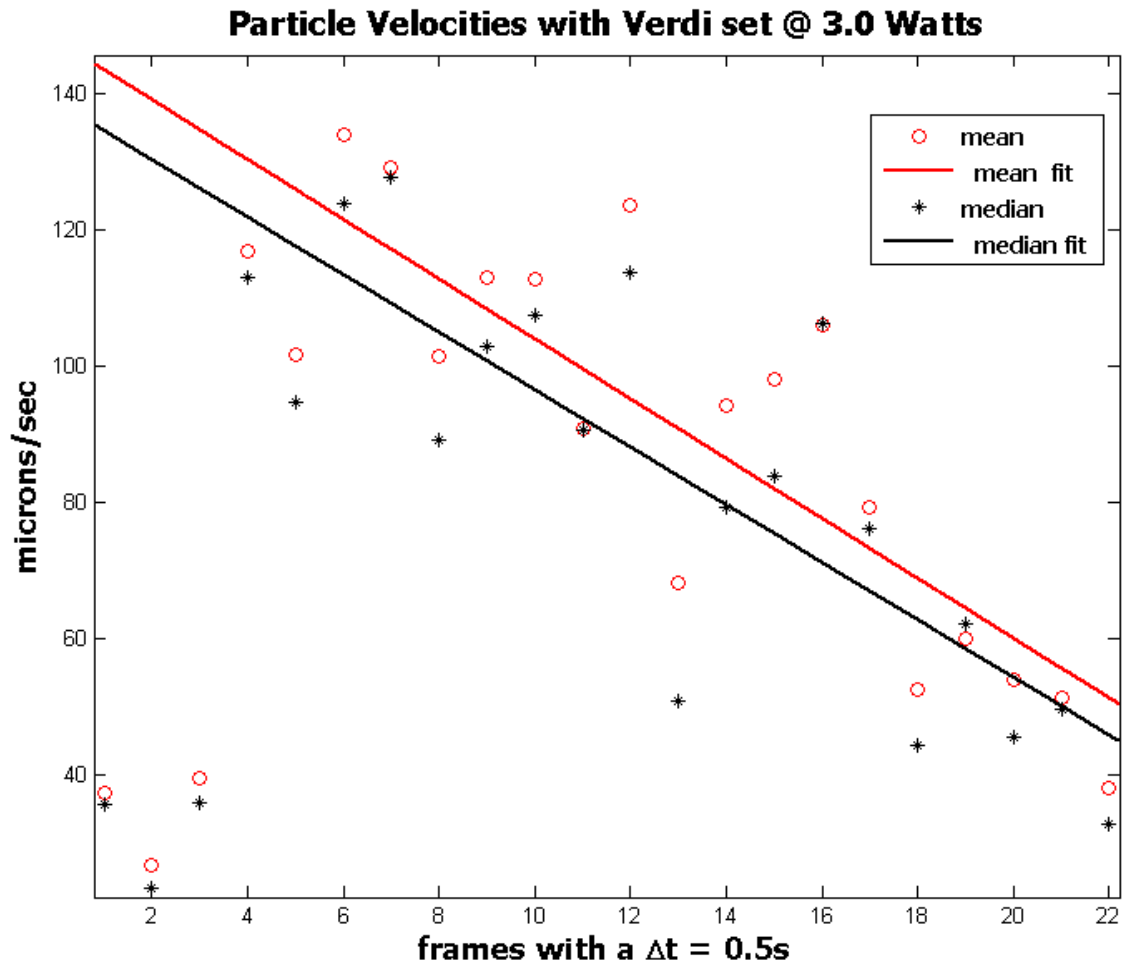


Figure 7: Malemine formaldehyde particle velocities

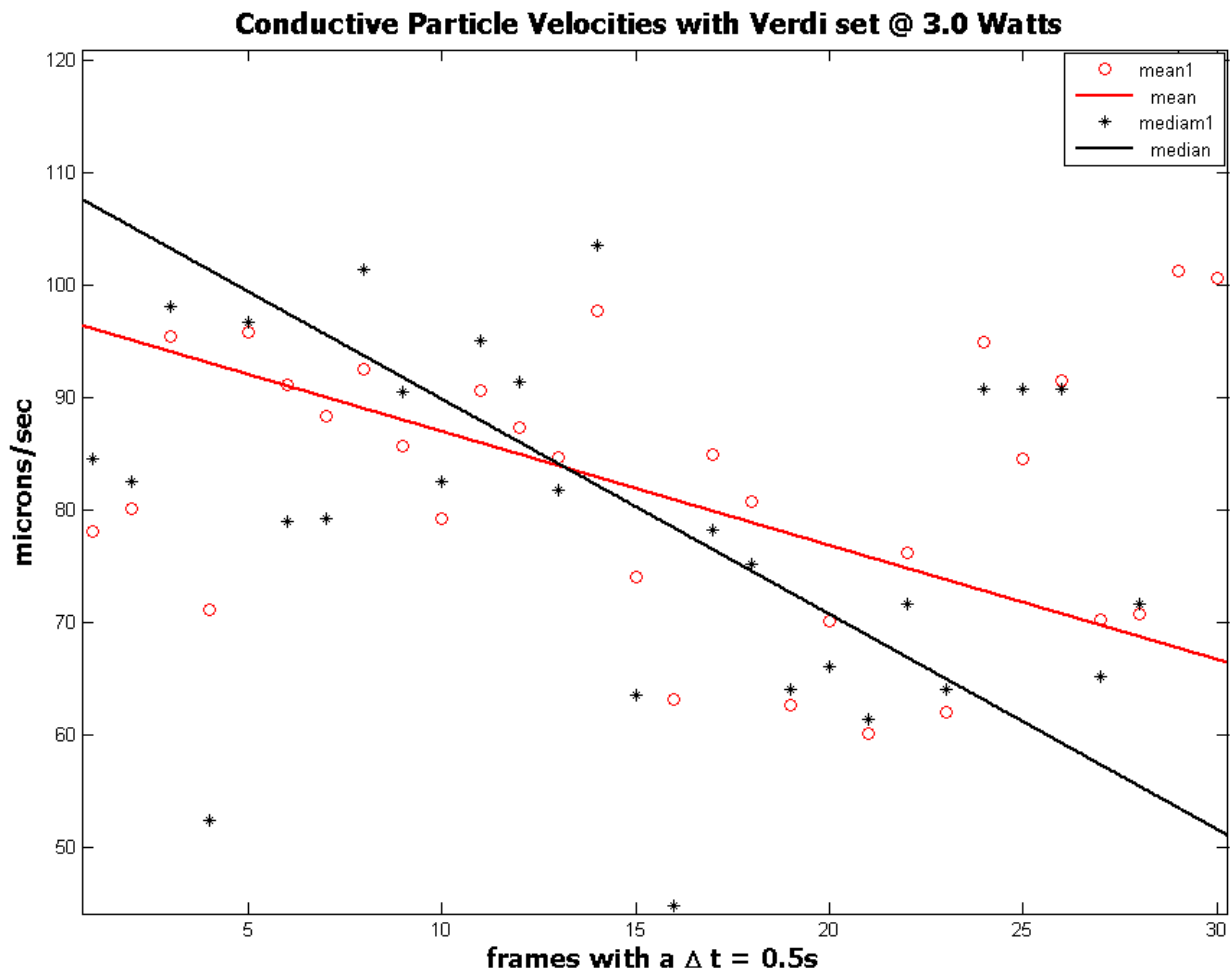


Figure 8: Gold coated malemine formaldehyde particle velocities

## My RET Experience

This has been a fantastic experience for me. My academic background in plasma physics has increased a hundred fold. I have discovered a program, JPIV that is a free Internet download and is suitable for my students. I have collected thousands of frames of images, some of which will be analyzed by my students using JPIV. I have also enjoyed the interactions with the CASPER HIDPL research group. I have gained much from this experience but I have also made some contributions to dusty plasma research. I have collected enough data to keep researchers busy for quite some time! Along with Jorge and Gary I have demonstrated that Mat PIV can be used: to process dust particle data, to reduce noise in images, for time resolution, and for filter processing. I have shown Jorge how ImageJ or Paint Shop Pro can be used for picture animation.



## Conclusions

- This has been a unique research experience at CASPER HIDPL.
- PIV software has been adapted to particle clouds in a plasma environment.
- Velocities of conductive and nonconductive particle clouds have been computed.
- It has been shown that JPIV could be implemented into the high school science curriculum.

## References

- [1] Laufer, R., Bock, D., Lachen-mann, M., Roeser, H.-P. & the LUNAR MISSION BW1 Project Team (2008) *IAC2008*, IAC-08-B4.8.05
- [2] [http://www.bs-sports.co.jp/english/science\\_of\\_golf\\_ball/science\\_of\\_ball\\_3.html](http://www.bs-sports.co.jp/english/science_of_golf_ball/science_of_ball_3.html)
- [3] Adrian, R.J. (2005). Twenty years of particle image velocimetry, Experiments in Fluids, 39: 159-160
- [4] [http://en.wikipedia.org/wiki/Particle\\_image\\_velocimetry](http://en.wikipedia.org/wiki/Particle_image_velocimetry)
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