



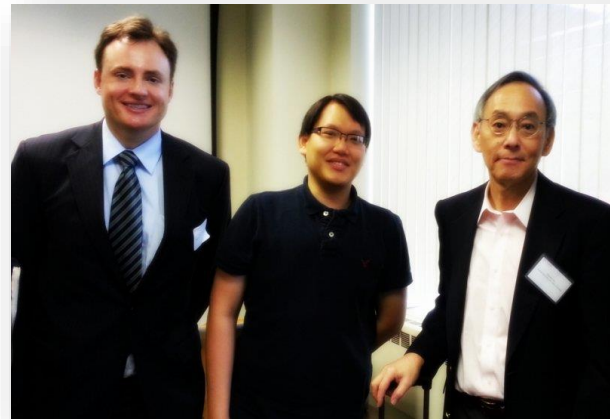
Lawrenceville Plasma Physics, Inc

High technology research, development and consulting in plasma physics, X-ray sources, and Focus Fusion

May 14th, 2013

## Summary:

- Plasmoid density triples, fusion energy rises with purer plasma
- But not pure enough—LPP tracks down what disrupted the filaments
- LPP has new paper for Spain conference
- US Department of Commerce finds all in order with LPP-Iran Scientific “Fusion for Peace” Collaboration
- LPP has rendezvous with Chu as Congress sets eye on ITER costs



L-R: LPP's Derek Shannon, Rutgers grad student Hadi Halim, and physics Nobel laureate and former Secretary of Energy Stephen Chu at the [Rutgers Energy Institute Symposium](#) on May 7<sup>th</sup>, 2013. See final section for more.

## Plasmoid density triples, fusion energy rises with purer plasma

The density of the fusion-producing plasmoid is the key factor that must be increased for LPP to demonstrate the scientific feasibility of net energy production from Focus Fusion—net energy meaning more energy out than is lost in making that energy. In the past month's experiments, LPP's research team has demonstrated the near-tripling of ion density in the plasmoid to  $8 \times 10^{19}$  ions/cc, or 0.27 mg/cc. At the same time, fusion energy output

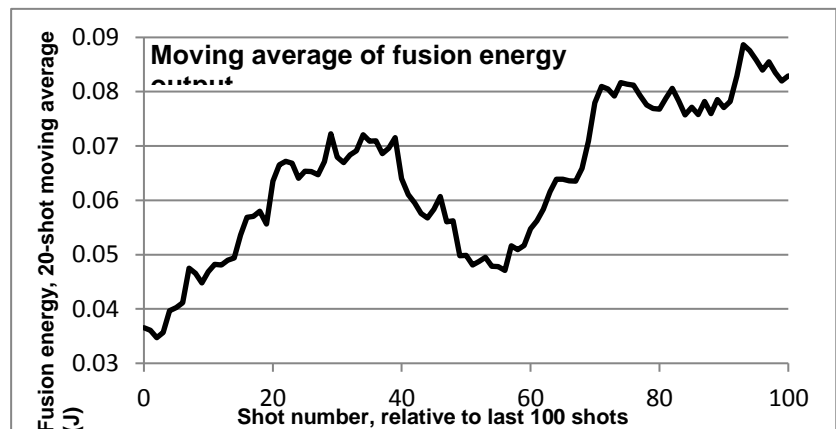
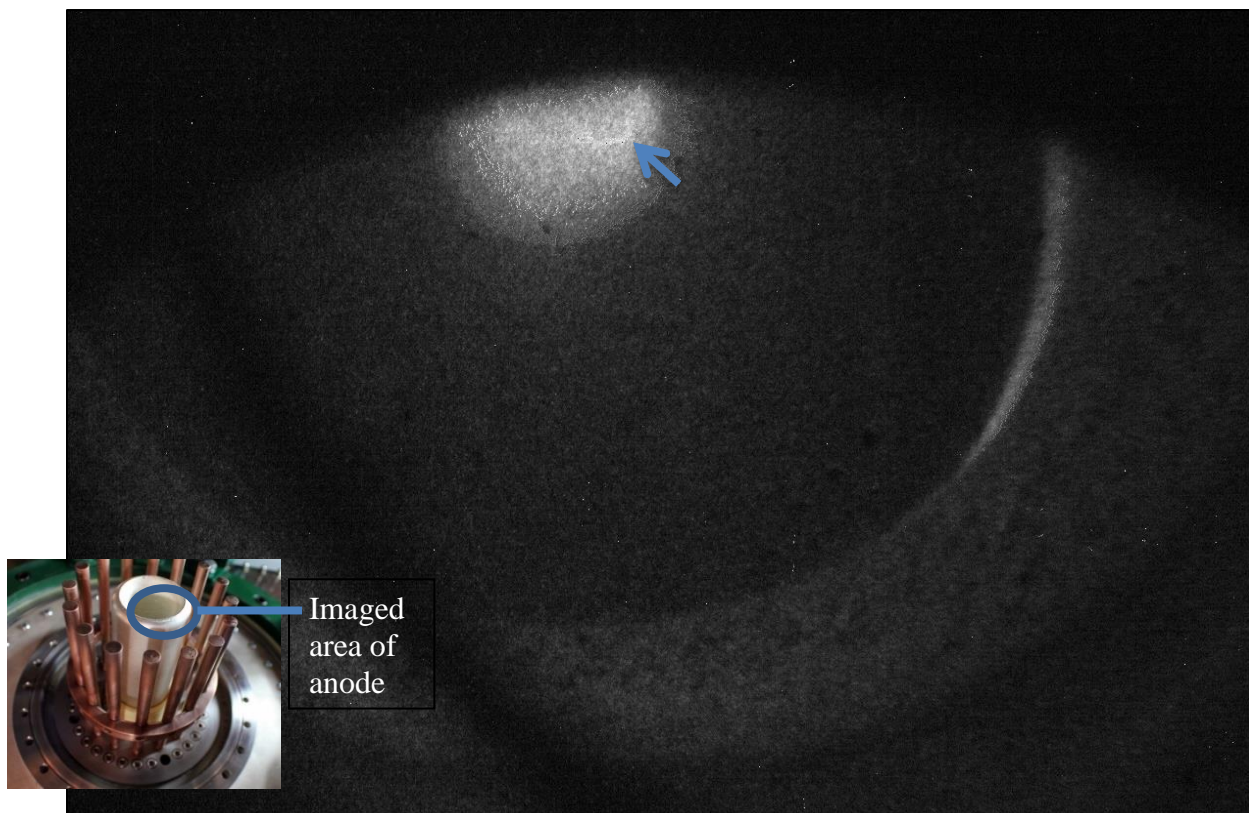


Figure 1. Fusion energy output in joules per shot (20-shot moving average) over the last 100 shots, primarily since late February, 2013. This graph somewhat understates the real increase in energy output, since it includes all shots, not just those with optimum conditions.

has moved up, with the best three-shot average increasing 50% to one sixth of a joule of energy. These results are not flukes, but part of an upward trend in density and energy since late February (see Figure 1), as the team reduced leaks in the vacuum chamber by over a hundred-fold. This reduced impurities entering the plasma from insulating oxide layers on the electrodes, thus improving the compression of the plasma. In addition, at the end of March, LPP's Derek Shannon refurbished the switches on FF-1, replacing worn plastic insulation, thus allowing the switches to fire in closer coordination.

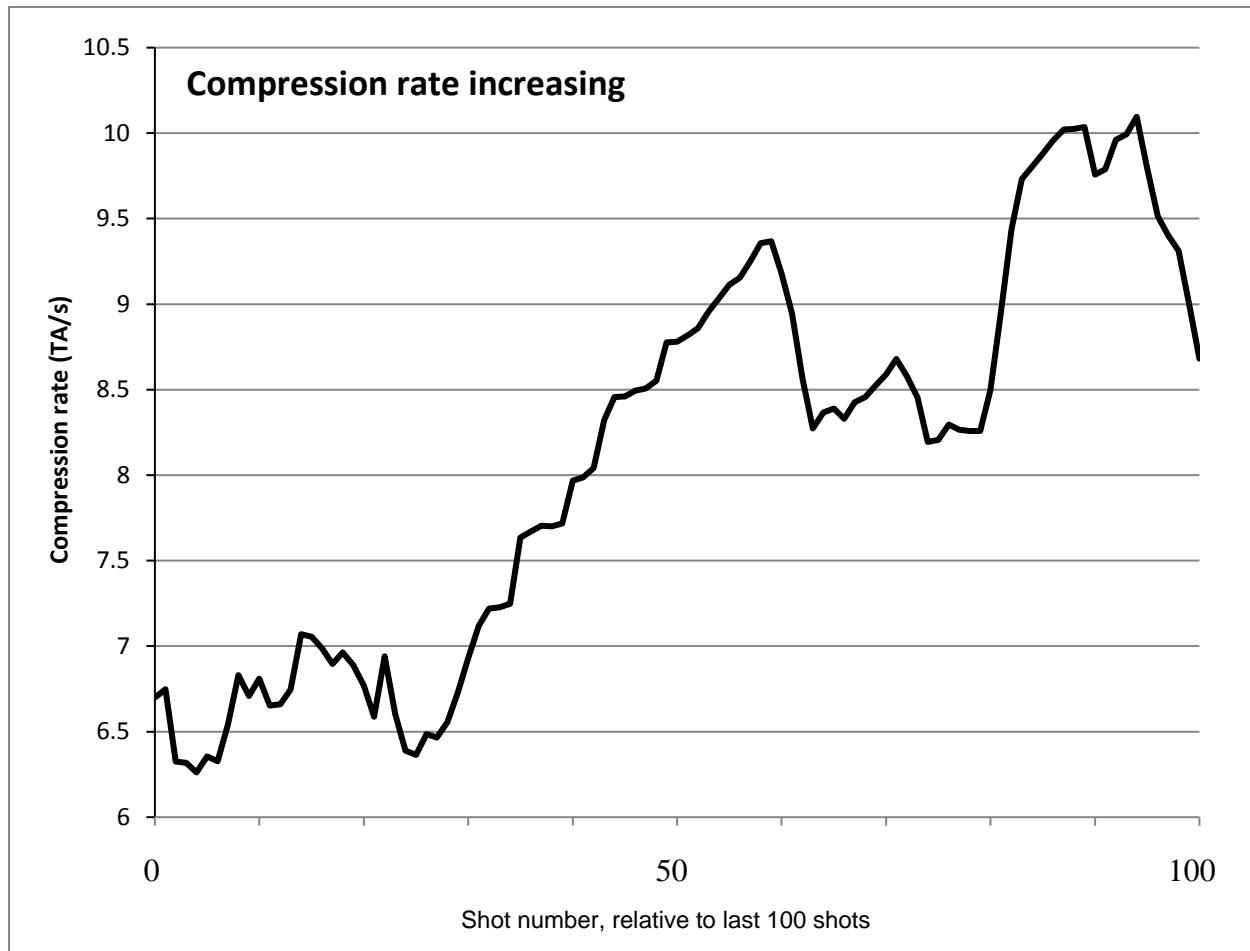
The greater increase in density than fusion energy is expected, because as compression improves and the plasmoid gets smaller, its lifetime also decreases. So while density improves roughly as  $1/r^3$ , where  $r$  is radius, lifetime decreases proportional to  $r$  and energy output increases roughly as the product of the two, or  $1/r^2$ .

The higher density was determined by combining measurements of the total fusion energy and ion temperature derived from our neutron detectors, and measurements of plasmoid size from our ICCD-camera images. The LPP team has moved the camera to a new position, looking up close to the axis of the electrodes instead of side-on as previously (see next section). Our very first image from this direction (Figure 2) shows our smallest plasmoid yet observed with a core radius of only 150 microns and core length of about 1.5 mm.



*Figure 2. First ICCD image looking up at end of anode, taken 2 ns before pinch on shot 1, May 2nd, 2013. The plasmoid core, foreshortened, is the bright thin thread (arrow) within the much larger bright blob. The dark circular region is the hole in the center of the anode and the black upper region is the boundary of the viewport.*

More evidence of increasing density comes from the increase in compression rate. The faster the rate, the smaller and denser the plasmoid. This rate is measured by the maximum rate of change of the current. Since late February, this measure has also increased by about 50%, consistent with a one-third decrease in plasmoid radius and a tripling of plasmoid density. (See Figure 3.)



*Figure 3. Compression rate in tera-Amps/second: the maximum rate of change of the current, which is a measure of how fast plasmoid compression occurs. The faster the compression, the smaller and thus denser the plasmoid. Density is expected to increase roughly as the cube of pinch depth. As in Figure 2, the last hundred shots are displayed.*

## **Plasma not quite pure enough: LPP tracking down what disrupted the filaments**

While the yield and density improvements show we are moving in the right direction, they are still well below what the LPP team theoretically expects for our present peak current of 1.1 MA. Yield is low by a factor of 10 and density by a factor of nearly 100. If we can get yield up to our theoretical expectation of over 1 joule, our scaling calculations tell us that with higher current we can make it all the way to the 30,000 J that we need to demonstrate scientific feasibility.

We've long concluded that this gap between theory and results is caused by the "early beam phenomenon" which is itself a symptom of the current sheath splitting in two, feeding only half its power into the plasmoid (see next section for more on this). Our new ICCD images looking up the barrel of the electrodes gave us new clues, as we were able to image the current sheath earlier in the pulse. The biggest surprise was that we saw no narrow filaments in the sheath. The filaments—tiny whirlwinds of plasma only tens of microns in diameter—are the first step in plasma compression. Without them, the plasma sheath is much thicker—about 2mm—and turbulent. It is thus vulnerable to corrugation instabilities that split it up into two sheaths.

This only pushed the puzzle back further. We knew from the tracks left by the filaments on the cathode plate (Figure 4) that the filaments existed early in the pulse. So, we had a mystery: what disrupted the filaments?

There was a second clue. We found that the pulse length—the time from the start of the pinch until the sheath collapsed into the pinch—was 15% too long compared with simulations of this phase done by Dr. Sing Lee, one of the leaders in the plasma focus field.

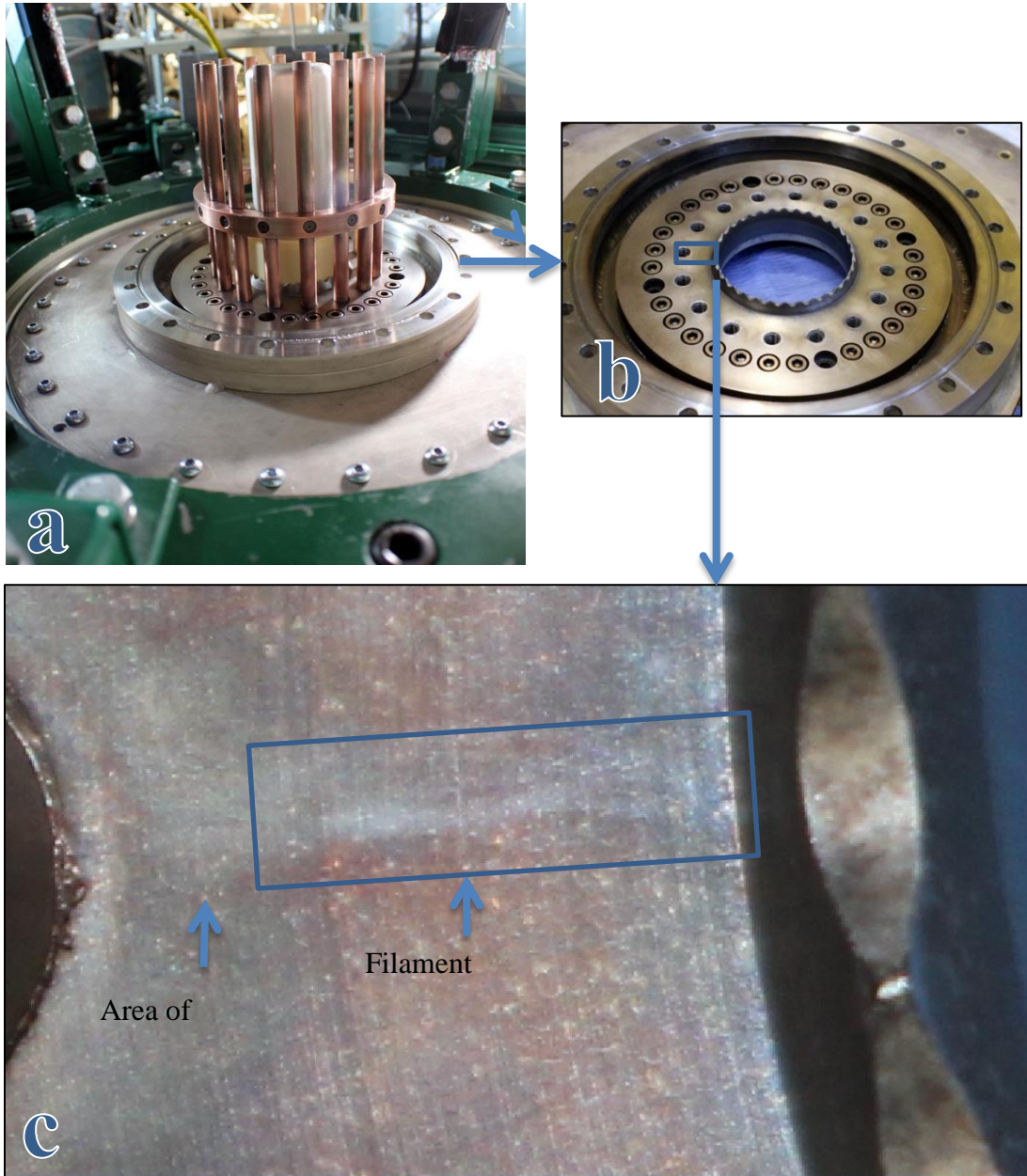
Both the lack of filaments and the longer pulse length could be explained by turbulence caused by metal impurities. If heavy metals got into the filaments, they would drop the viscosity of the plasma, allowing turbulence to disrupt the filaments. The same turbulence would dissipate energy, slowing down the sheath and making the pulse time too long.

So with oxidation way down and the leaks fixed, where were these metal impurities coming from? We had to take the electrodes apart to find out, and then analyze the dark deposits we found with an X-ray spectrometer (provided by local company NJ Plating). That pointed to the likely culprit: tiny amounts of silver and copper were being vaporized by micro-arcing at the base of the cathode rods, where silver-coated copper washers were located. While the amount vaporized was tiny—about 0.2 milligram per shot—the current sheath only has a mass of 2 milligrams, and we calculate disruption can occur with even 60 micrograms contamination.

In the next shot series, we will replace the washers with indium wire which has worked elsewhere on our electrodes to entirely eliminate even the tiniest arcing. We will also silver-plate the cathode rods as we have done with the anode. Over the longer run, we are looking at ways to have a single-piece cathode made out of tungsten or tungsten-copper in order to eliminate the rod-plate joint altogether. These steps should get rid of the filament disruption for good, enabling results to catch up with theory.



*Figure 4. Disruption of the filaments. The cathode plate (right) at 7.5" in diameter is shown for context below, with rods, insulator, and anode in **a**, and alone with close-close up area outlined in **b**. In **c**, the close-up of the cathode plate runs from the tungsten teeth at right to a copper rod at left. Bright blue marks trace the paths of filaments from 60 shots, showing that the filaments at this point are only about 150 microns in radius. (The abrupt change in the blue marks' brightness is due to a change in the tungsten surface.) Note how the filament paths spread out and eventually are disrupted as they approach the band of evaporated silver and copper near the rod.*



## **LPP to present results at ICPIG conference in Spain**

Some of LPP's latest results will be presented at the International Conference on Phenomena in Ionized Gases, ICPIG, in Grenada, Spain, in July. A paper by the LPP research team has already

been accepted for publication in the conference proceedings. The main results reported came from a recent analysis of ICCD images and other data, which showed that the current sheath had split into two sheaths prior to the pinch. The inner sheath could not produce a true pinch, due to the attraction of the outer sheath. Instead, it produced a jet-like blob at low density, as well as the early beam. Once the jet had moved out of the way, the outer sheet collapsed into the pinch. But since part of the current was still flowing through what had been the inner sheath, the main pinch was deprived of energy. If half the current was in each sheath, the yield would decrease by a factor of 16-32, explaining the lower yields with the early beam. Subsequent to the submission of this paper, the new research reported in the previous section of this report shows that the double sheath phenomenon is itself in all probability due to the destruction of the filaments, producing a thicker turbulent sheet much more vulnerable to the instabilities that produce the double sheath.

## **US Department of Commerce finds all in order with LPP-Iran Collaboration**

Back on December 19<sup>th</sup>, 2012, the website “Forbidden Knowledge TV” published an imaginative report saying that LPP had developed fusion generators and was selling them for \$70,000 apiece, including six to Iran. This misinformation was based on an earlier post by Gordon Duff at Veterans Today. We contacted both sites and were able to get corrections published. However, the “exports to Iran” misinformation caused the Department of Commerce and the FBI to investigate LPP’s cooperation agreement with the Plasma Physics Research Center in Iran. After LPP had given the Department of Commerce the correct information—that we were not exporting anything and that the cooperation agreement was for scientific publications exempt from sanctions, the agent involved told us that the matter was closed and settled to their satisfaction. LPP had previously ascertained that our scientific collaboration with colleagues in Iran was lawful, but it is always good to get official agreement. We look forward to further progress that decreases the chances of conflict by setting an example of peaceful cooperation while accelerating fusion research.

## **A rendezvous with Chu as Congress sets eye on ITER costs**

Nobel laureate Stephen Chu, who stepped down as Secretary of Energy on April 22<sup>nd</sup>, was the keynote speaker at the Rutgers Energy Institute Symposium on May 7<sup>th</sup>. LPP’s Derek Shannon was able to chat at length about LPP’s achievements and challenges with Chu, although the secretary is prohibited from lobbying the department he formerly led. In May 2012, the current Energy Secretary, Ernie Moniz, was in attendance and [received LPP’s latest papers while serving as a member of the President’s Council of Advisors on Science and Technology](#). LPP will update the Department of Energy and its Office of Fusion Sciences as our work progresses. In other fusion policy developments, a bipartisan quartet of senators—including Senator Ron Wyden, the [focus of LPP’s call for fusion hearings](#)—has requested that the [General Accountability Office investigate the costs of the ITER tokamak](#). LPP hopes this will lead to greater support for a more diverse fusion program that includes both the tokamak and cheaper alternatives such as the plasma focus device.