

Streaked Visible Spectroscopy Data Reduction Manual

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ABSTRACT

I describe the data reduction procedure for the Streaked Visible Spectroscopy (SVS) diagnostic at the *Z* Pulsed Power Facility at Sandia National Laboratories. This procedure utilizes Interactive Data Language (IDL) and is tailored for the purposes of the White Dwarf Photosphere Experiment (WDPE). The intended audience is someone working with the data from this project at Sandia or at the University of Texas, particularly graduate and undergraduate students. For context, I provide some background on the SVS diagnostic and how it is used in the WDPE.

1. Introduction

The *Z* Pulsed Power Facility (Matzen et al. 2005) at Sandia National Laboratories boasts a number of instruments to diagnose its experiments (e.g., Nash et al. 2001; Lake et al. 2004; Jones et al. 2006; Gomez et al. 2012). We refer to these systems as diagnostics. The main diagnostic we use for the White Dwarf Photosphere Experiment (WDPE) is Streaked Visible Spectroscopy (SVS), which is the same as spectroscopy at optical wavelengths except with an extra dimension – time. A number of *Z* experiments have used different forms of this diagnostic (e.g., Bailey et al. 2000; Dunham et al. 2004; Bailey et al. 2008; Falcon et al. 2010), though it continues to evolve, thus necessitating the use of the latest documentation for accurate data processing.

We currently have three SVS systems. Each system consists of a spectrometer, which provides the wavelength dispersion, and a streak camera which provides the time dispersion. The first and second systems, SVS1 and SVS2, are made up of identical components (i.e., same model spectrometer, streak camera, etc.) and record data onto film, while SVS3 has a different model spectrometer/camera and records onto a CCD. This document applies to SVS1 and SVS2. We will neglect SVS3 from here on.

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The pulsed power accelerator, also known simply as Z , is located in the high bay of building 983. SVS is not in the high bay, which allows us to field this diagnostic while the pulsed power shot fires (because the high bay is evacuated and locked up prior to a shot). It is still technically located in building 983 in the Laser Target Bay, one of the buildings housing the Z -Beamlet laser (Rambo et al. 2005). Though the laser folk refer to this building as the Target Bay, the convention for people working on experiments at Z , including us, is to call it “Phase C”, a vestige of site development over the past decade.

Table 1 lists the relevant personnel associated with SVS and includes contact information. Though there is overlap amongst the listed roles, the primary focus of the Responsible Scientist is to guide the development of the diagnostic based on the science needs. The Responsible Individual procures and develops. The Diagnostic Specialist maintains, and the Operations Personnel (who is also the Diagnostic Specialist in this case) fields the instrument. As an experimenter, currently my role includes some of all of these duties.

SVS Personnel

ROLE	PERSON	ORGANIZATION	TELEPHONE (#)	EMAIL (@sandia.gov)
System Manager	Gregory Rochau	1675	505.845.7540	garocha
Responsible Scientist	Matthew Gomez	1643	505.284.6944	mrgomez
Responsible Individual	David Bliss	1675	505.844.4137	debliss
Diagnostic Specialist	Alan Carlson	1675	505.845.7190	alcarls
Operations Personnel	—	—	—	—
Film Development	Linda Nielsen-Weber	1675	505.284.8838	lbniels

2. SVS in the WDPE

Our experiment takes place in a large (2200 ft³) vacuum chamber at the center of Z . We place a gas cell assembly a distance away from an x-ray source, a z -pinch dynamic hohlraum (Spielman et al. 1998; Nash et al. 1999; Sanford et al. 2002; Bailey et al. 2006; Rochau et al. 2008) (Figure 1). The z -pinch x-rays irradiate the gas cell, transmit through a thin ($1.44 \pm 0.02 \mu\text{m}$) Mylar window, and are absorbed by a gold wall at the back end of the cell cavity (Figure 2). The heated gold re-emits as a Planckian surface with a temperature of \sim few eV, heating the hydrogen through photoionization.

We observe the hydrogen plasma along lines of sight perpendicular to the z -pinch radiation and parallel to the gold wall using lens-coupled optical fibers, which deliver the light to the SVS systems. The optical fibers are high OH silica core/clad step-index multimode fibers with a 100 μm core diameter and a numerical aperture of 0.22 ± 0.02 . The spectrometer in each system is a 1 m focal length, $f/7$ aperture Czerny-Turner design (McPherson, Inc. model 2061). The streak camera

(EG&G model L-CA-24) sweeps the spectrum over ~ 450 ns with $\sim 1 - 2$ ns temporal resolution. A micro-channel plate intensifier (Ladislas Wiza 1979) amplifies the phosphor emittance exiting the camera, and Kodak T-MAX 400 film records the output. See Falcon et al. (2013) for a detailed description of the experimental platform.

Now to the hands-on part.

3. Procedure

We use the programming language IDL along with PFIDL, a suite of IDL routines developed at Sandia. It is necessary that you do this work on a machine that has these installed.

Do not fear the length of this document or the seemingly infinite number of steps. I am being verbose and detailing many tiny things so that this can be used as a reference. The necessary IDL commands are listed in `unfold_svs_v2.pro`. Once you become accustomed to the procedure, it should suffice to use that as a guide without much need, if any, for this document.

- If this is your first time to reduce data, create a directory for data reduction.
- Under your data reduction directory, create a directory for the shot dataset you wish to reduce and name after the shot number (e.g., `z2410`).
- Copy raw data image files (`.pff`) to this new directory, leaving the original raw data undisturbed in their own directory. These files include a single step wedge image, which includes a `gr` (for “green”) in the name (e.g., `z2410_svsgr.pff`) and a streak image (time-resolved spectrum) for each SVS.

(Note: Data from experiments performed before November 2011 have only one streak image since SVS2 was not yet implemented. If only one streak image exists for an experiment performed after November 2011, then we failed to obtain data from one of the systems.)

(Note: Older data may have `osvs` in the filename instead of `svs`. Don’t let that trip you up. Before it was called Streaked Visible Spectroscopy, it was Optical Streaked Visible Spectroscopy, which is obviously redundant. The update in the name was a welcomed modification.)

- We are now working in this new shot directory. Rename files so as to remove all underscores, otherwise the placement of underscores will confuse a particular routine later on.
- Create a text file for SVS1 named `regrid1.txt`. Fill with text using the following convention but corresponding to your particular shot. Do the same for SVS2:

```
fit file
z2410svsgr.fit
```

```

in
z2410svs1.pff
out
z2410svs1_sub.pff

```

3.1. Convert Film Density to Radiant Exposure

A Perkin-Elmer microdensitometer digitizes the T-MAX 400 film data. We convert film density to units of radiant exposure (erg cm^{-2}) using a NIST-calibrated step wedge.

- Open the IDL Workbench and make your working directory the shot directory under your data reduction directory.
- Open `unfold_svs_v2.pro`. This is not a routine to be executed but rather a sequence of IDL commands. We will now go through those commands.

To access help in IDL, type `?` into the command, and press **Return** (or **Enter**). To access help for PFIDL commands specifically, use the command `lhelp`. PFIDL is a library of routines developed primarily by Paul Mix at Sandia for processing data from many *Z* diagnostics.

- Type `ALT_WEDGE,PATH=1` into the command line and press **Return** (or **Enter**). The program will print `Open the step wedge file you wish to fit` and prompt you to press **Return** to continue, for which it will print `r to c`.

(Note: IDL commands are not case-sensitive. I am capitalizing functions and their options in this procedure because that is the convention I use in my syntax for organizational purposes.)

- Press **Return**, and choose the appropriate image file from the dialog box (e.g., `z2410svsgr.pff`).
- Follow the commands to flip the image in the *y* direction by typing `f`, pressing **Return**, typing `y`, and pressing **Return**. The steps in the image will now appear to become brighter to the right with the top half brighter than the bottom half.
- The program will ask again if the image needs to be rotated or flipped. It now needs neither. Press **Return** to continue.
- `does image need to be cropped? (y/n)`
I know. It is misspelled. And the first letter is not capitalized. It bugs me, too. Yes, the image needs to be cropped. Type `y`, and press **Return**.
- In the window that pops up, draw out a rectangle within the plot region that includes all the steps but excludes the superfluous regions to the left and right by clicking in one corner, dragging, and clicking in the opposite corner.

- Click `Accept / Save Image` and then `Done / Exit`.
- We will use the `winstr` command to get an average background level in the film. Press **Return** to continue.
- Draw out a rectangle in the bottom left of the image where the signal is lowest and constant. Exclude major artifacts. The width may be a couple or even a few step-widths wide. You will not be able to discern the difference between the steps in this region. That is the point. Click `Accept / Save Image` and then `Done / Exit`.
- A dialog box will prompt you to choose a Film Exposure file. You should have a few choices. Use Table 3.1 below to choose the appropriate one. The appropriate one will always have “gr” in the filename. If the dialog box does not automatically bring you to the correct directory, the Film Exposure file will be found under the `Exposure_Values` directory which should be under `pfidl/programs/`.

Step Wedge Calibrations

STEP WEDGE TEXT FILE	VALID DATA RANGE	VALID SHOT RANGE
<code>expgr012303</code>	04.23.2003 – 04.18.2011	
<code>expgr051611_209</code>		<code>z2183 – z2199</code>
<code>expgr051811_AI-11_0004</code>		<code>z2199 +</code>

- Hit any key to continue...
(Where’s the any key?)
- Did `pe_cal` routine get lineouts to your satisfaction? (y/n)
A plot of two curves resembling stairs will appear. The answer to the question is almost always y (and press **Return**). You cannot do much if it is unsatisfactory besides redoing the cropping. Inpainting would perhaps be a nice technique (e.g., Elad et al. 2005), but that is not included here.
- A plot appears showing all the step wedge values connected by a dashed line with film density on the horizontal axis. Because of the scaling, the interesting “linear” regime is not immediately visible. Here you may delete a spurious point or two if they significantly deviate from the trend (this would be evident in the previous plot as well), but usually you will take no action. Click `Done - Exit`.
- A plot pops up of film density versus radiant exposure with a fit curve. Also a window appears where you can manipulate the fit. Make the fit as smooth as you can. Update changes by clicking `Calculate`. Almost always you will never need to do more than changing the degrees of the polynomials to 5. Sometimes you may need to change the break values. It is not necessary to change the number of breaks from 2 since the plot clearly shows three regimes:

an exponential trend at low film density, a quasi-linear trend at intermediate film density, and an exponential trend at high film density. The range of radiant exposure values we will be using resides in the intermediate regime, so this is the most important part to fit. The lowest values are typically swallowed up in the noise, and we rarely encounter the higher values. You will notice that in the intermediate regime where the step wedge values overlap, they often do not do so satisfactorily. This is a systematic effect that remains under investigation. Do the best you can in spite of this.

- Click **Save to File** and enter the filename as the name of the step wedge image file but with a `.fit` suffix instead of the `.pff` (e.g., `z2410svsgr.fit`). This is the same filename that you entered into the “regrid” text file earlier (e.g., `regrid1.txt`).
- Click **Okay** and then **Quit / Exit**.
- **What file name for the vida file?**
Type the same filename you just entered for the fit but without any suffix (e.g., `z2410svsgr`). This step is obsolete, but please humor the program for the time being.
- Type **REGRID** into the command line and press **Return**.
- **What is the filename of the text input file to be read?**
Enter the name of the “regrid” text file (e.g., `regrid1.txt`). Press **Return**.
- **Default regrid value is set to 2**
Do you wish to change it? (y/n)
Type **n** and press **Return**.
- **is this level acceptable? (y/n)**
Type **y** and press **Return** (or press **Return** to continue). There is really nothing straightforward to change even if the level was not acceptable.
- A window appears plotting the image. To establish the background level, draw out a rectangle in one of the corners outside of the streak image proper where the signal is lowest. Avoid artifacts. Click **Accept / Save Image** then **Done / Exit**.
- **Use this level or a user specified value? (n to change)**
Yes. Press **Return** to continue.
- Repeat the **REGRID** steps for SVS2 if necessary.

3.2. Align Streak Image

- Specify the shot name (e.g., `Shot = 'z2410'`) and instrument name (e.g., `SVS = 'SVS1'`) corresponding to the data you are about to process. We will use these later.

- Open the exposure-corrected streak image file (e.g., `z2410svs1_unp.pff`) by selecting the appropriate file in the dialog box window:

```
OPENPFF
```

- Read the structure dataset into structure array 1:

```
READSTR,1
```

- `CLOSEPFF`

- Specify a level range for the radiant exposure as a 2-element array. Use the following as an initial guess:

```
LevRange = [0.,0.1]
```

- Plot the streak image. Adjust `LevRange` as necessary:

```
PLOTSTR,1,LEV=LevRange,/ASPECT
```

Be sure you can identify the following features:

- *Impulse* – a single laser pulse exposed onto the film during the shot which we use as a timing fiducial to relate the data to the history of the z pinch and to data recorded with other spectrometer systems. It appears as a small dot and is usually at the bottom of the streak image and on the lefthand side.
 - *Comb* – a stream of equally-spaced laser pulses exposed onto the film during the shot used to set the scale of the time axis and to correct for any time warpage that may occur throughout the streak sweep. These pulses are arranged vertically.
 - *Lasers* – continuous (in time) emission lines exposed onto the film prior to the shot used to determine the wavelength dispersion, instrumental profile, and instrumental spectral resolution. These lines are vertical. They correspond to 4579 Å (blue) and 5435 Å (green). Select older data may not include the blue laser, and some of the oldest data may include a red laser at 6328 Å.
- Align the streak image with respect to one of the laser lines, and save into a new structure (2) using the command `ALIGNSTR,1,2,LEV=LevRange`. A plot window will appear. Click on the bottom end of one of the laser lines and then on the top end. After the second click, the routine will plot the feature along with a linear fit. If the feature appears curved, redo with the other laser line. (This kind of curvature is likely due to barrel distortion of the image. We will correct for this in the wavelength direction later.) If the feature appears to have data points that significantly deviate from the trend, the routine is likely having difficulty determining the centroid of the feature in that region because it cannot distinguish the feature from the background signal. Try redoing this step, and adjust where you click so as to avoid regions where the feature may be blending into the background. This likely means, for your first click, starting above (after) the onset of x-rays and thus plasma formation in our data (time is increasing in the upward direction).

3.3. Apply Time Axis

We will analyze the measured comb pulse spacing from the streak image using a fast Fourier transform (FFT) and use this to apply a time dispersion to the vertical axis. The impulse will provide an absolute timing reference.

- Extract a vertical lineout from the streak image (structure array 2) over the comb using the command `LINSTR,2,LEV=LevRange,/VERTICAL`. A window pops up plotting the streak image. Specify a name for this lineout by entering 201 in the `WDF Array` text field. Move your cursor over the plot such that the lineout spans the length of the comb and click. Click `Accept / Save Image` then `Done / Exit`.
- Plot the lineout, wdf array 201:
`PL0,201`
- Select the boundaries over which to compute the FFT using `XCUR,xpp`. A plot window appears. Make two clicks with your cursor – the first at the start (leftmost) of the lineout just inside where the pulses start and the second at the end (rightmost) of the lineout just inside where the pulses end. Click `Done`.
- Remove the regions outside of the boundaries you specified from wdf array 201:
`LIM,201,xpp(0),xpp(1)`
- Use the command `APPLYCOMB,2,3,201,COMB=5.,INT=10,SWEEP=430.` to compute the FFT of wdf array 201 to figure the time dispersion and apply this time dispersion to the streak image (structure 2) and save as a new image (structure array 3), thus converting the vertical axis to units of time in ns. “COMB=5.” specifies that the intrinsic comb spacing is 5 ns (we set the comb generator to 5 ns spacing). “INT=10” is the number of Y Position intervals over which to compute FFTs. We are actually computing multiple FFTs throughout the comb in order to correct for any time warpage or any slowing or quickening of the streak camera sweep. “SWEEP=430.” gives an initial guess for the duration of the sweep. As many plots will appear as INT while the routine finds the peak frequency at each interval. The last plot to appear is Y Position versus the calculated Time Dispersion with a 2-degree polynomial fit. This fit typically curves upwards. Make sure that it looks half-way decent. (I understand that this command is quite subjective. Don’t worry. We will address this in time.) If it does not, repeat this step while varying INT.
- Extract a vertical lineout from the streak image (structure array 3) over the impulse using the command `LINSTR,3,LEV=LevRangem,/VERTICAL`. Name this lineout 202 in the `WDF Array` text field. Select the slope of the lineout to be `vertical`. Move your cursor over the plot such that the lineout passes over the impulse and click. Click `Accept / Save Lineout` then `Done / Exit`.

- Use `ZOOMW,202,XC=xp` to identify the time of the impulse. A double plot window appears. Use the left plot to zoom in on the impulse. Adjust the region by clicking in the left plot window or by toggling `Center of ZOOM region` at the top of the window. Adjust the magnification by toggling `Log of ZOOM Magnification`. In the right plot window, right click at half the maximum amplitude of the impulse on the rising side (earlier in time) of the impulse. (This is the standard convention when measuring time from signals.) Click `Quit`.
- Specify the impulse time for this shot number and SVS system. (It may be the same for SVS1 and SVS2.) The impulse time is the `VISSPECIMP` (“Visible Spectroscopy Impulse”) value. If you do not know this value, simply use some default value for now, such as 0 or 1000.
`ImpTime=[VISSPECIMP value]`
- Apply this offset to the time axis of the streak image (structure array 3):
`CHASTR,3,AYD=ImpTime-xp(0)`

3.4. Apply Wavelength Axis

I will describe two ways to convert the horizontal axis to units of wavelength. The first determines the wavelength dispersion for a single horizontal lineout and applies it to the entire image. This is the method we have been using in the past. The second way cuts the streak image into lineouts, determines the wavelength dispersion for each lineout, and applies it to each one. This should correct for any barrel distortion of the image in the wavelength direction. It also includes a (so-so) determination of the uncertainty due to the wavelength dispersion, and it determines the instrumental profile. The latter method automates more work, but since it is newer and since I’m a mediocre coder at best, it is not robust and likely still has a few loose screws banging around.

Use only one of these methods. If you choose the second, skip to Section 3.4.2.

3.4.1. Method A: Image Approach

- Extract a horizontal lineout from the streak image (structure array 3) that intersects the laser lines and is near the (vertical) middle of the image using the command
`LINSTR,3,LEV=LevRange,/HORIZONTAL`. Name this wdf array 203.
- Identify the centers of first the bluer laser and second the redder laser:
`ZOOMW,203,XC=xp`

For most of our experiments, the spectrometers are configured such that blue and green lasers appear in the data. No shots before February 2012 use the blue laser (because we didn’t have it). Some early shots include a red laser. If the data has only one laser (or none), then we must (reluctantly) use some other line(s) as the wavelength fiducial(s). This may be the $H\beta$ line itself. Modify the following step accordingly.

- Determine the wavelength dispersion using the two lines you identified above:
 $WDisp = ([redder\ line\ wavelength\ in\ \text{\AA}] - [bluer\ line\ wavelength\ in\ \text{\AA}]) / (xp(1) - xp(0))$

Wavelength Fiducials		
LINE	λ (\AA)	$\delta\lambda$ (\AA)
Blue	4579	0.5
(H β)	(4861.323)	(0.001)
Green	5435.161	0.06
Red	6328	0.5

- Copy the streak image to a new structure array (4) and apply the wavelength dispersion:
`XFRSTR,3,4`
`CHASTR,4,MXD=WDisp`
`CHASTR,4,AXD=[bluer line wavelength in \AA]-xp(0)*WDisp`
- Create a filename to save the time- and wavelength-corrected streak image (e.g., `FileName=Shot+SVS+'_cor.pff'`). Notice that `FileName` must be a string data type:
`CREATEPFF,FileName`
- Write structure array 4 to the `.pff` file:
`WRISTR,4`
- `CLOSEPFF`

3.4.2. Method B: Lineout Approach

- Create a filename to save the time-corrected streak image (e.g., `FileName=Shot+SVS+'_tcor.pff'`). Notice that `FileName` must be a string data type:
`CREATEPFF,FileName`
- Write structure array 3 to the `.pff` file:
`WRISTR,3`
- `CLOSEPFF`
- You will use the function `LineByLine.pro` to extract wavelength-corrected lineouts. This function requires some input parameters (shown in the next step). To determine some of these, use `LINSTR,3,LEV=LevRange,/HORIZONTAL` to view the streak image. Do not extract a lineout here. Simply use the cursor to determine coordinates (displayed in the top left part of the window).

- For `StartTime`, find an early time for which a horizontal lineout intersects both laser lines. It does not need to be the absolute earliest time, because data at the edges is often undesirable, so a few ns buffer will suffice.
- For `EndTime`, find the same as for `StartTime` except near the end of the streak.
- For `GuessBlue` and `GuessGreen`, find the horizontal positions (in microns) of these laser lines. The names for these are arbitrary. You may change them if you use different wavelength fiducials.

(Note: `LineByLine.pro` is currently only able to handle wavelength fiducials that are emission lines.)

- Define the following variables to be used as input for the function `LineByLine.pro`:

```
StartTime = [from above]
EndTime = [from above]
TimeRange = [StartTime, EndTime]
TimeWidth = 5.
GuessBlue = [from above]
GuessGreen = [from above]
Guess = [GuessBlue, GuessGreen]
W_Lasers = [4579.D, 5435.161D]
W_Lasers_E = [0.5D, 0.06D]
```

Open up `LineByLine.pro` to see a more complete description of the arguments. In this example, I set `TimeWidth` to 5 ns. This is the width of the lineout or the length of time over which you're integrating. The smaller this is, the better you are resolving the time evolution of the data and the worse the signal-to-noise ratio of each spectrum. Due to the temporal resolution of the SVS systems, it is not useful to set `TimeWidth` $\lesssim 2$ ns. The laser wavelengths are also listed in the table in Section 3.4.1 (the section I told you to skip if you chose Method B). Above I listed the values corresponding to the blue and green lasers. Adjust these as necessary according to which wavelength fiducials you use.

- Extract wavelength-corrected lineouts into a 2-dimensional array named `SPowArr`, where the first dimension is the array of spectral power values (corresponding to wavelength), and the second dimension specifies the lineout. (It is not necessary to define `SPowArr`. The function will do it for you.):

```
SPowArr = LineByLine(3, TimeRange, TimeWidth, Guess, $
W_Lasers, W_Lasers_E, Wave, Time, WAVEE=WaveE)
```

This function also returns the wavelength array (`Wave`) in Ångstroms corresponding to `SPowArr` for all lineouts, and the times (`Time`) for each lineout. The optional parameter `WaveE` is the uncertainty of `Wave` at each element.

When you run `LineByLine.pro`, a plot window appears displaying the determined wavelength dispersion versus time, and you are prompted:

What shall I do?

- (1) Revise GUESS parameters and try again
- (2) Specify lineouts with problems and try again
- (3) Nothing. I am satisfied. Get me out of here!

If the points are not smooth, that is, if they display any sharp discontinuities or “jumps”, the function needs to try again, so try option (1). The function will plot the measured centroid positions of the laser lines as a function of time, revealing which centroids deviate from the straight line, if any. The plot will be oriented so as to mimic the layout of our reduced streak data with time increasing upwards. If the function is having problems determining the wavelength dispersion, it is because it is measuring a bad centroid for one of the laser lines or perhaps both. Indicate to the function which laser line(s) need revision, and it will run again using revised GUESS parameters. It will default to using the median centroid value as the new GUESS. If this is reasonable (if the median value is passing through the majority of the centroids in the plot), then allow the function to do this. Otherwise, indicate no, and it will use a different approach to determine the new GUESS involving the peak of the distribution of measured centroids.

If there are isolated lineouts that appear problematic, you may try option (2) and follow the instructions. This disregards the fit for that lineout and simply uses the mean of adjacent lineouts. After the function runs again, if it still shows non-smooth points, you may try option (1) or (2) more times. Once you are satisfied, exit the routine by selecting option (3). If you are not satisfied, you’ll need to execute the function again after exiting and fiddling (I apologize for the technical jargon) with input parameters. The function is having difficulty determining the wavelength dispersion for some lineouts probably because there are additional peaks in the vicinity of the lasers lines that are interfering with the function’s ability to determine the centroids of the the laser lines. You may try adjusting `Guess`. This will move the fitting window independently for each wavelength fiducial. You may also adjust the optional parameter `GuessWidth`, which sets the widths of these fitting windows.

- Extract the instrumental profile for the streak dataset by measuring each laser fiducial:

```
Result = EXTRACT_INST(Wave, SPowArr, WLasers, Time, FWHM_0, FWHM_1)
```

This returns two 2-dimensional arrays, `FWHM_0` and `FWHM_1`, corresponding to the bluer and red-der lasers, respectively. The first dimension contains an array of full-width-at-half-maximum (FWHM) fit values for different lineouts. The length of this array is be less than or equal to the total number of lineouts from `ExpArr`. There won’t necessarily be a measured FWHM for each lineout because not all the fits will be good fits. Since we do not expect the instrumental profile to change throughout the streak (an assumption), our strategy here is to use each lineout as an independent measurement of the instrumental profile and then determine an average. The second dimension has five elements and specifies the fit parameter. In ascending order, these are: Gaussian FWHM, uncertainty of Gaussian FWHM, Lorentzian FWHM, uncertainty of Lorentzian FWHM, and Voigt FWHM. We know (from fitting) that the in-

strumental profile is best described as a Voigt profile, which is a convolution of a Gaussian and a Lorentzian. One can define a Voigt function according to the Gaussian and Lorentzian FWHMs.

Examples:

`FWHM_0[34,2]` is the measured Lorentzian FWHM of the bluer laser for the 34th lineout.

`FWHM_1[* ,4]` is the array of measured Voigt FWHMs of the redder laser for all lineouts.

`EXTRACT_INST.pro` prompts some interaction. It plots the measured FWHM values (Gaussian and Lorentzian) versus time (lineout) and for each laser. It then asks:

Would you like to remove a point? (y/n)

Like with `LineByLine.pro`, some fit values may be suspect, but unlike `LineByLine.pro`, since we're interested in average values, we do not necessarily need a successful fit for every single lineout. Remove the points that we know are bad. For instance, on some streak images, the impulse will overlap the blue laser. When this happens, `EXTRACT_INST.pro` has little or no hope of fitting the profile of the blue laser for a lineout at that time.

If you choose to remove a point:

For the bluer or redder laser? (b/r)

Give element number:

It is not necessary to precisely count points on the plot. After you choose a number, it asks:

This one? (y/n)

If you're off, try again. The function will keep asking you if you would like to remove points until you say no.

Instead of removing individual points, you may want to remove everything beyond a certain cutoff time. This is useful because the measured fit parameters apparently change after the onset of the continuum (once the x-rays arrive at the party). I suspect this is because that, although the fitting routine accounts for a background when performing the fit, it still struggles to accurately separate it from the Voigt profile. The function asks:

Introduce time boundary for fit values? (y/n)

You may enter a time for the bluer laser:

Enter time boundary for bluer laser:

and for the redder laser:

Enter time boundary for redder laser:

To give no time boundary, enter a time value outside the range of the streak or simply hit **Return**. It prints average measured fit values when it completes its process.

You may specify the half-width (in Å) of the fitting window using the optional input parameter `WIDTH=Width` in the call to `EXTRACT_INST.pro`, where `Width` is a two-element array corresponding to each wavelength fiducial. You may also circumvent being asked about the

time boundary by using the optional input parameter `T_CUTOFF=T.Cutoff`, where `T.Cutoff` is a two-element array specifying the time boundary (in ns) for each wavelength fiducial.

(Note: While using `EXTRACT_INST.pro` to determine the instrumental profile does a decent job, I'm still working on this method. I've noticed that the ability to fit the laser lines with a Voigt profile depends upon the size of the fitting window. As the window size increases, apparently so does the fitted Guassian width. The Lorentzian width decreases, and the Voigt width holds constant. Letting the window size increase until convergence is not so simple, however, since the larger the window, the more susceptible one is to interlopers such as contaminant lines that may interfere with the fit.)

- Rename the FWHM fit value arrays to describe the lasers to which they correspond:

```
FWHM_Blue = FWHM_0
```

```
FWHM_Green = FWHM_1
```

The `EXTRACT_INST.pro` routine does not do this automatically, because the two lasers it uses to determine the wavelength dispersion do not necessarily need to be the blue and green lasers.

- Save the values as an IDL save file:

```
SAVE, Wave, WaveE, SPowArr, Time, FWHM_Blue, FWHM_Green, $
```

```
FILENAME='work\'+'Shot'+SVS+' .var'
```

Congratulations! You are now ready to do science! Or maybe just more data reduction...

Thank you to Sean R. Moorhead for additional edits.

A. Appendix: SVS System Components

Figure 3 is the SVS system schematic. This does not include any changes that occurred after March 2012, particularly the implementation of SVS3, which added some connections and another fiberoptic splitter. Do not trust the exact delay generator channel connections as illustrated here. The red lines are optical fibers. The black lines are coaxial cables. The numbers correspond to the components listed in Table A.

REFERENCES

- Bailey, J. E., Asay, J., Bernard, M., Carlson, A. L., Chandler, G. A., Hall, C. A., Hanson, D., Johnston, R., Lake, P., & Lawrence, J. 2000, *J. Quant. Spec. Radiat. Transf.*, 65, 31
- Bailey, J. E., Chandler, G. A., Mancini, R. C., Slutz, S. A., Rochau, G. A., Bump, M., Buris-Mog, T. J., Cooper, G., Dunham, G., Golovkin, I., Kilkenny, J. D., Lake, P. W., Leeper, R. J.,

- Lemke, R., Macfarlane, J. J., Mehlhorn, T. A., Moore, T. C., Nash, T. J., Nikroo, A., Nielsen, D. S., Peterson, K. L., Ruiz, C. L., Schroen, D. G., Steinman, D., & Varnum, W. 2006, *Physics of Plasmas*, 13, 056301
- Bailey, J. E., Knudson, M. D., Carlson, A. L., Dunham, G. S., Desjarlais, M. P., Hanson, D. L., & Asay, J. R. 2008, *Phys. Rev. B*, 78, 144107
- Dunham, G., Bailey, J. E., Carlson, A., Lake, P., & Knudson, M. D. 2004, *Review of Scientific Instruments*, 75, 928
- Elad, M., Starck, J. L., Querre, P., & Donoho, D. L. 2005, *Appl. Comput. Harmon. Anal.*, 19, 340
- Falcon, R. E., Rochau, G. A., Bailey, J. E., Ellis, J. L., Carlson, A. L., Gomez, T. A., Montgomery, M. H., Winget, D. E., Chen, E. Y., Gomez, M. R., & Nash, T. J. 2013, *High Energy Density Physics*, 9, 82
- Falcon, R. E., Rochau, G. A., Bailey, J. E., Ellis, J. L., Montgomery, M. H., Winget, D. E., Gomez, M. R., & Leeper, R. J. 2010, in *American Institute of Physics Conference Series*, Vol. 1273, American Institute of Physics Conference Series, ed. K. Werner & T. Rauch, 436–439
- Gomez, M. R., Rochau, G. A., Bailey, J. E., Dunham, G. S., Kernaghan, M. D., Gard, P., Robertson, G. K., Owen, A. C., Argo, J. W., Nielsen, D. S., & Lake, P. W. 2012, *Review of Scientific Instruments*, 83, 100000
- Jones, B., Deeney, C., Coverdale, C. A., Meyer, C. J., & Lepell, P. D. 2006, *Review of Scientific Instruments*, 77, 100000
- Ladislas Wiza, J. 1979, *Nuclear Instruments and Methods*, 162, 587
- Lake, P. W., Bailey, J. E., Rochau, G. A., Moore, T. C., Petmecky, D., & Gard, P. 2004, *Review of Scientific Instruments*, 75, 3690
- Matzen, M. K., Sweeney, M. A., Adams, R. G., Asay, J. R., Bailey, J. E., Bennett, G. R., Bliss, D. E., Bloomquist, D. D., Brunner, T. A., Campbell, R. B., Chandler, G. A., Coverdale, C. A., Cuneo, M. E., Davis, J.-P., Deeney, C., Desjarlais, M. P., Donovan, G. L., Garasi, C. J., Haill, T. A., Hall, C. A., Hanson, D. L., Hurst, M. J., Jones, B., Knudson, M. D., Leeper, R. J., Lemke, R. W., Mazarakis, M. G., McDaniel, D. H., Mehlhorn, T. A., Nash, T. J., Olson, C. L., Porter, J. L., Rambo, P. K., Rosenthal, S. E., Rochau, G. A., Ruggles, L. E., Ruiz, C. L., Sanford, T. W. L., Seamen, J. F., Sinars, D. B., Slutz, S. A., Smith, I. C., Struve, K. W., Stygar, W. A., Vesey, R. A., Weinbrecht, E. A., Wenger, D. F., & Yu, E. P. 2005, *Physics of Plasmas*, 12, 055503
- Nash, T. J., Derzon, M. S., Chandler, G. A., Fehl, D. L., Leeper, R. J., Porter, J. L., Spielman, R. B., Ruiz, C., Cooper, G., McGurn, J., Hurst, M., Jobe, D., Torres, J., Seaman, J., Struve, K., Lazier, S., Gilliland, T., Ruggles, L. A., Simpson, W. A., Adams, R., Seaman, J. A.,

- Wenger, D., Nielsen, D., Riley, P., French, R., Stygar, B., Wagoner, T., Sanford, T. W. L., Mock, R., Asay, J., Hall, C., Knudson, M., Armijo, J., McKenney, J., Hawn, R., Schroen-Carey, D., Hebron, D., Cutler, T., Dropinski, S., Deeney, C., Lepell, P. D., Coverdale, C. A., Douglas, M., Cuneo, M., Hanson, D., Bailey, J. E., Lake, P., Carlson, A., Wakefield, C., Mills, J., Slopek, J., Dinwoodie, T., & Idzorek, G. 2001, *Review of Scientific Instruments*, 72, 1167
- Nash, T. J., Derzon, M. S., Chandler, G. A., Leeper, R., Fehl, D., Lash, J., Ruiz, C., Cooper, G., Seaman, J. F., McGurn, J., Lazier, S., Torres, J., Jobe, D., Gilliland, T., Hurst, M., Mock, R., Ryan, P., Nielsen, D., Armijo, J., McKenney, J., Hawn, R., Hebron, D., Macfarlane, J. J., Petersen, D., Bowers, R., Matuska, W., & Ryutov, D. D. 1999, *Physics of Plasmas*, 6, 2023
- Rambo, P. K., Smith, I. C., Porter, Jr., J. L., Hurst, M. J., Speas, C. S., Adams, R. G., Garcia, A. J., Dawson, E., Thurston, B. D., Wakefield, C., Kellogg, J. W., Slattery, M. J., Ives, III, H. C., Broyles, R. S., Caird, J. A., Erlandson, A. C., Murray, J. E., Behrendt, W. C., Neilsen, N. D., & Narduzzi, J. M. 2005, *Appl. Opt.*, 44, 2421
- Rochau, G. A., Bailey, J. E., Maron, Y., Chandler, G. A., Dunham, G. S., Fisher, D. V., Fisher, V. I., Lemke, R. W., Macfarlane, J. J., Peterson, K. J., Schroen, D. G., Slutz, S. A., & Stambulchik, E. 2008, *Physical Review Letters*, 100, 125004
- Sanford, T. W. L., Lemke, R. W., Mock, R. C., Chandler, G. A., Leeper, R. J., Ruiz, C. L., Peterson, D. L., Chrien, R. E., Idzorek, G. C., Watt, R. G., & Chittenden, J. P. 2002, *Physics of Plasmas*, 9, 3573
- Spielman, R. B., Deeney, C., Chandler, G. A., Douglas, M. R., Fehl, D. L., Matzen, M. K., McDaniel, D. H., Nash, T. J., Porter, J. L., Sanford, T. W. L., Seaman, J. F., Stygar, W. A., Struve, K. W., Breeze, S. P., McGurn, J. S., Torres, J. A., Zagar, D. M., Gilliland, T. L., Jobe, D. O., McKenney, J. L., Mock, R. C., Vargas, M., Wagoner, T., & Peterson, D. L. 1998, *Physics of Plasmas*, 5, 2105

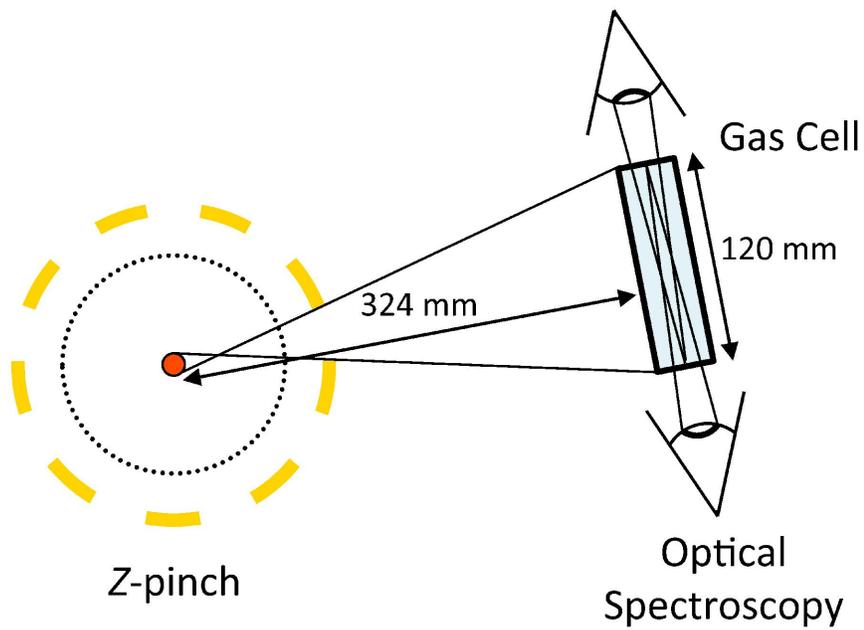


Fig. 1.— Figure from Falcon et al. (2013). Top view schematic of the experimental setup inside the vacuum chamber. The gas cell sits 324 mm away from the z pinch. We observe the hydrogen plasma along lines of sight perpendicular to the x-rays.

SVS System Components List

No.	SVS	NAME	VENDOR	MODEL	SERIAL NO.
1		O/E Converter	Highland Technology	J730-1 Fiberoptic-to-Electrical Converter, 21A730.1B	0218
2a		Master Delay Generator	Stanford Research Systems	DG535 Digital Delay and Pulse Generator	11641
2b	1	Camera Delay Generator	–	–	02238
2c	2	–	–	–	11669
3a		Impulse Generator	NSTec	H-OE-51 Time Mark/Impulse Generator 13	311691-011
3b		Comb Generator	–	–	311691-009
4a		Fiberoptic Splitter	Thorlabs	FCMM50-50A	3378014
4b		–	–	–	3378001
4c		–	–	–	3377944
5		Oscilloscope	Tektronix	DPO3054 Mixed Signal Oscilloscope	C012496
6		USB Flash Drive	Edge Tech	DiskGo Classic, 2GB	...
7a	1	Spectrometer	McPherson	2061 1-m focal length f/7 Czerny-Turner Monochromator	58
7b	2	–	–	–	46
8a	1	Streak Camera	EG& G	L-CA-24 Streak Camera	208
8b	2	–	–	–	221
	1	Streak Camera Power Supply	EG& G	L-PS-36	013
	2	–	–	–	102
	1	Streak Camera Power Supply Monitor	EG& G	L-ME-5	23
	2	–	–	–	17
9		Blue Laser	Modu-Laser	Stellar-Pro 457/4.5 Argon Ion Laser	ML0623P R411AC0
10		Green Laser	CVI Melles Griot	05-LGR-193 Green Cylindrical Helium Neon Laser	6090FF
		Green Laser Power Supply	CVI Melles Griot	05-LPL-903-065 Laboratory Helium Neon Laser Power Supply	62066
11		Red Laser	JDS Uniphase	1122 Helium Neon Laser Head	772337
		Red Laser Power Supply	JDS Uniphase	1202-1 HeNe Laser Power Supply	492-730
12		Transit Fiber Bundle	PolyMicro		...
13		Chamber Feed-through	PolyMicro		...

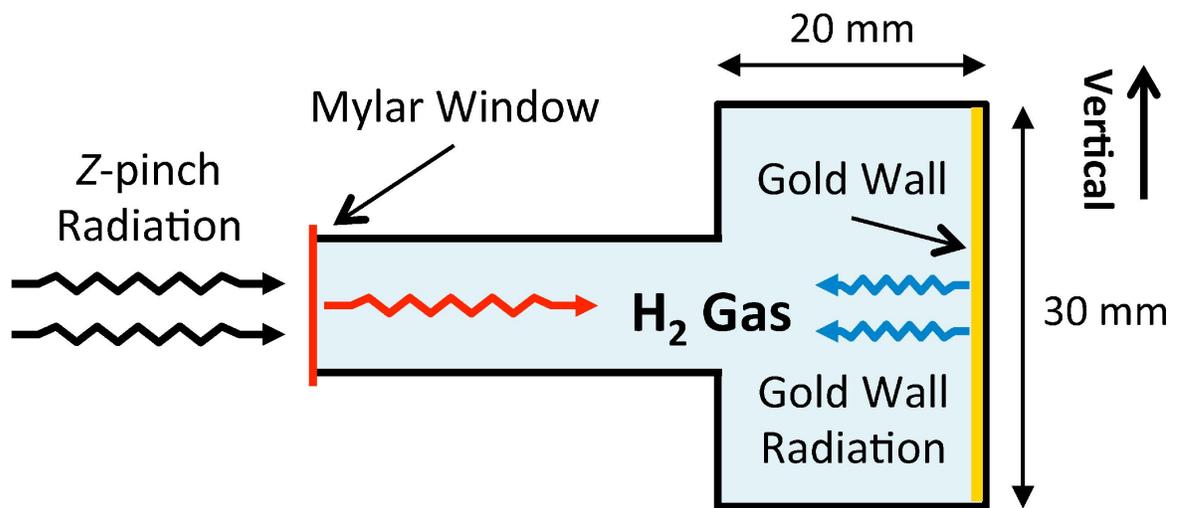


Fig. 2.— Figure from Falcon et al. (2013). Observing line of sight view (perpendicular to incident radiation) schematic of the gas cell cavity cross-section. Z-pinch x-rays transmit through the Mylar window and are absorbed by the gold wall at the back end of the cell cavity. The gold wall re-emits to heat the hydrogen gas.

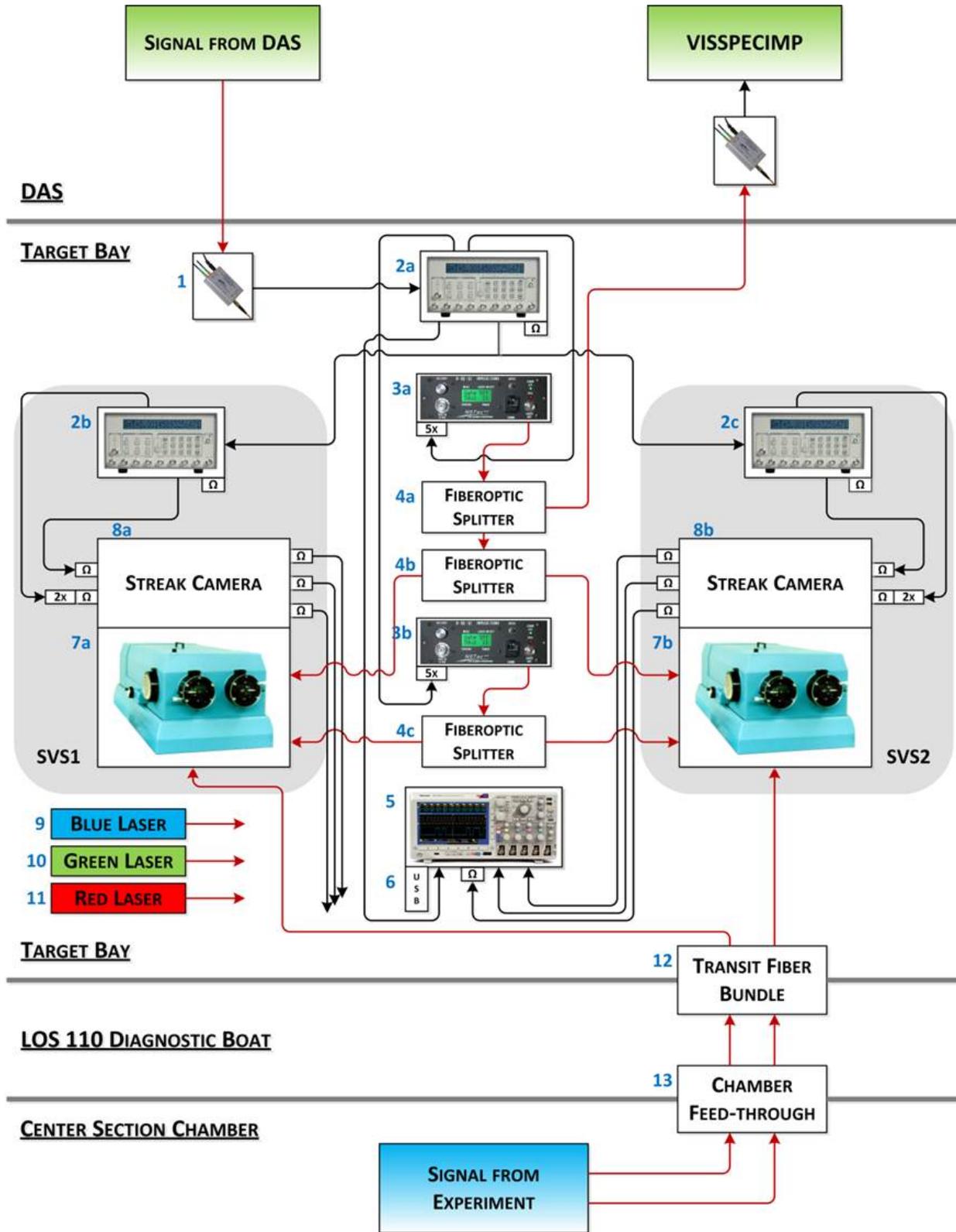


Fig. 3.— Schematic of the SVS system.