

Version: #1

# Standard Operating Procedure

## THOR Lab Operations



**Texas Center for High Intensity Laser  
Science University of Texas at Austin**

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## 1 Introduction:

This document outlines procedures for safe operation of the THOR lab (RLM 12.210). It is not intended as a comprehensive safety manual, and does not replace institutional laser safety training. To qualify for work in this lab, this document must be read and signed. Proper performance of these procedures is mandatory to be a qualified THOR laser user in good standing. While it is our goal to provide engineered controls to physically limit the possibility of accident, these can not ensure by themselves a completely safe environment. Personnel and visitors must therefore adhere to safe standard operational procedures.

It is expected that everybody in the lab is concerned for each other's safety, BUT each person is ultimately responsible for their own safety. If any worker in the lab has a concern regarding safety, that worker is qualified to safely halt work until such time that there is no cause for concern.

## 2 Visitors and Qualified Personnel

There are two main categories of people that may enter the lab, described in this section. The categories are:

### 2.1 Visitors

Visitors are allowed temporarily in the lab, or who are new and have not yet received on-site laser safety training. Before they enter the lab when the laser is running, visitors must be notified of the safety considerations and protocol required during their time in the lab before they can enter the lab. Visitors read and sign the visitor sign-in sheet before entering the lab. Visitors shall be escorted in the lab at all times by a member of the Qualified Lab Personnel. New workers in the lab can become Qualified Lab Personnel after a period of 1 week (see below).

### 2.2 Qualified Laser Users and Operators

There are two levels of qualified laboratory personnel: qualified laser users (QLU) and qualified laser operators (QLO). These designations are explained below.

#### 2.2.1 Qualified Laser User (QLU)

Qualified laser users can enter the lab unescorted while the laser is operating. The status of QLU is reserved for regular lab workers or visiting researchers. To become a QLU, institutionalized laser safety training either at UT or at their home institution is required, and the person must have received instruction about the safety hazards and protocol specific to the THOR laser (site-specific training OH102 from TCHILS staff). QLUs may perform experiments once the laser is operating, and may train with a QLO on the THOR laser in order to become a QLO (see below). QLUs may work on the THOR lab laser itself only when directly supervised (i.e. in the presence of) by a QLO.

### 2.2.2 Qualified Laser Operator (QLO)

Qualified laser operators have additional training and experience on the THOR laser. QLOs are qualified to operate, maintain, or align at least parts of laser system in accordance with this document on a daily basis. All employees of the group are expected to attain QLO status shortly after becoming secondary RI's on some aspect of the system (see Section 4).

## 3 Safety Protocol

### 3.1 Goggles

Each person qualified to work in the THOR lab is given their own set of laser goggles, which have been carefully determined to provide the best balance of optical protection and visibility. While darker goggles provide better protection at all potential wavelengths, other problems such as trip hazards become more likely as visibility is reduced.

#### 3.1.1 Location

Goggles are located in the goggle rack by the THOR lab entrance, within the **Error! Reference source not found.**, which is where they are kept when not actually being worn. This means that they are not lying anywhere in the lab or taken out of the lab. This helps to maintain the goggles in good condition and keeps them from becoming lost.

#### 3.1.2 Daily Use Goggles

For daily use, we currently use UVEX LOTG-YAG/KTP goggles. Their specifications are given below. An O.D. of 7 indicates that 1 out of  $10^7$  photons is expected to get through the plastic.

Name	Style	Vendor	Most Relevant O.D.			Visibility (%)	Price
			532	800	1064		
UVEX -- LOTG-YAG/KTP	LOTG or LSK	Lase-R-Shield	7	3	10.6	24	~280 (lasermate.com)

We have these goggles in two styles, shown in Figure 1 and Figure 2 (colors are not the same as ours). We commonly refer to these goggles as “brown goggles.” They are very effective against 532- and 1064-nm radiation, and moderately effective against 800 nm radiation.

We strive to stay abreast of current safety eyewear development that fulfills our desire for maximum radiation protection, visibility, and a minimum of the “photobleaching” effect, which is the nonlinear absorption effect that renders the goggle ineffective against ultrashort pulse radiation.



Figure 1 LOTG style daily use goggle.



Figure 2 LSK style daily use goggle.

### 3.1.3 Alignment Goggles

Personnel especially trained in the alignment of the laser oscillator may use special “alignment” goggles, shown in Figure 3. These are designed to mildly protect against the green light while allowing visibility of the weak 800-nm oscillator light.

Name	Style	Vendor	Most Relevant O.D.			Visibility (%)	Price
			532	800	1064		
GPT YAG/532AL	LGF	Lase-R-Shield	>2	NA	NA	40	



Figure 3 LGF style alignment goggle.

### 3.1.4 Care and handling

The goggles need to be cared for to keep them clean and free from scratches or other surface damage. To maximize their lifetime:

- Store goggles in the designated goggle rack in a way that does not scratch them, i.e., face-up or in their original containers.
- Clean them periodically using a mild cleaning solution and a soft cloth or lens tissue. DO NOT USE ACETONE.

### 3.1.5 Goggle Inspections

Inspect your goggles **before each use**. Discard the goggle and order a new pair if they fail this inspection. Check for:

- Clarity: Look for permanent damaged on any of the transparent plastic. Besides compromising the effectiveness of the goggles, damaged surfaces can reduce visibility
- Fit: The goggles need to fit securely and leave very little space through which a beam can enter the space between the goggles and your eye.

### 3.1.6 Protocol

Upon receiving new goggles:

- ⇒ Inspect the goggles.
- ⇒ Label the goggles with your name.
- ⇒ Label a space in the goggle rack with your name.
- ⇒ Fill out the goggle logbook.
- ⇒ If you haven't done so, sign the goggle acknowledgement sheet in the back section of the THOR Lab SOP.

## 3.2 Laser Inventory

This section includes all lasers, amplifier stages, and pulse compressors in the THOR laser, including their classification and output characteristics. Below is a summarizing table of their output parameters and descriptions of how each laser is placed in the overall system.

### 3.2.1 Summary of Laser Parameters

The parameters of each element are summarized in Table 1.

Element name	Wave-length	FWHM bandwidth	Pulse Energy	Pulse rep. rate	Pulse width	Avg. power (peak power)
Millennia Vs J	532 nm	Narrow	CW	CW	CW	5.5 W
Femotosource s20	800 nm	20 nm	~ 8 nJ	75 MHz modelocked	20 fs modelocked	720 mW (CW) (.4 MW)
Big Sky CFR 400 (SHG output)	532 nm	Narrow	~ 230 mJ	10 Hz	< 9 ns	1.5 W (~25 MW)
Regen amplifier	800 nm	30 nm	~ 4 mJ	10 Hz	~ 535 ps (chirped)	10 mW (2 MW)
4-pass amplifier	800 nm	30 nm	~ 23 mJ	10 Hz	~ 535 ps (chirped)	70 mW (14 MW)
GCR PRO 350 (SHG output)	532 nm	Narrow	1.4 J	10 Hz	6-11 ns	14 W (1.4 GW)
5-pass amplifier	800 nm	30 nm	≤ 1.1 J	10 Hz	~ 535 ps (chirped)	11 W (2 GW)
Vacuum compressor	800 nm	30 nm	≤ 600 mJ	10 Hz	40 fs	≤ 6 W (≤ 15 TW)
Air compressor	800 nm	30 nm	≤ 120 mJ	10 Hz	40 fs	≤ 1.2 W (≤ 3 TW)
Quantel Brilliant <sup>to</sup>	1064 or 532 nm	Narrow	400 mJ 200 mJ	10 Hz	5 ns or 4 ns	4 W (80 MW) 2 W (50 MW)
Alignment lasers	808 nm	Narrow	CW	CW	CW	≤ 100 mW

HeNe lasers	632.8	Narrow	CW	CW	CW	$\leq 10$ mW
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**Table 1 Summary of laser hazards.** NOTE: Values shown are approximate and should not be used to characterize system performance



### 3.2.2 Description of major laser components:

#### **Millennia VsJ (class 4)**

This commercial laser pumps the Femtosource oscillator. In normal operation, the beam path to the oscillator is partially enclosed with beam tubes, but it remains a class 4 laser. An enclosure surrounding this and the Femtosource laser can render these two lasers class 1, when a foil shutter is attached to the enclosure (see section 3.3.2).

#### **Femtosource Scientific s20 (class 4)**

The femtosource is a commercial Ti:Sapp Kerr mode-locked oscillator assembly pumped by the Millennia. The pulse train sets the master timing clock, and an optical shutter (the “slicer”) prior to the stretcher reduces the pulse rate from 75 MHz to 10 Hz. The stretcher then imparts a linear chirp that lengthens the pulses to several hundred picoseconds.

#### **Big Sky CFR 400 (class 4)**

This commercial frequency-doubled Nd:YAG laser pumps the regenerative and 4-pass amplifiers. The energy is split with a wave-plate and polarizer, such that the regen receives about 1/3 of the energy and the 4-pass receives the rest. Directly at the output of the unit, a dichroic mirror steers the  $2\omega$  light and transmits the residual  $1\omega$  into a beam dump. This is enclosed to minimize escaping  $1\omega$  light. The numbers given in Table 1 refer to Q-switched operation. Flashlamp operation puts out significantly less energy in a longer pulse, but is still a class 4 laser hazard.

#### **Regenerate amplifier (class 3B)**

The regenerate amplifier (“regen”) is a Pockels- cell switched Ti:Sapp laser cavity that is seeded by the femtosource pulses, post slicer and stretcher, and pumped by about 1/3 of the Big Sky energy (see above). The pulse makes about 20 round trips in the cavity before being switched out.

#### **4-pass bowtie amplifier (class 3B)**

This Ti:Sapp amplifier stage is seeded by the output of the regen and pumped by the remaining energy from the Big Sky. The 800 nm beam makes 4 passes through the crystal at slight horizontal angles, and the pump enters the crystal on-axis. The crystal is Brewster cut at 800 nm (very near Brewster for 532 nm) and some pump light reflects upwards into a square ND filter beam dump attached to the crystal mount. Pump light transmitted through the crystal is stopped on a razor stack beam dump.

#### **Spectra Physics PRO 350s (class 4)**

The THOR laser system uses two of these frequency-doubled Nd:YAG lasers to pump either side of the 5-pass crystal (see below). A dichroic mirror within the laser head transmits unconverted  $1\omega$  light into a beam dump and directs  $2\omega$  to the output. When uncovered for maintenance, the  $1\omega$  light, which can contain up to twice the energy as the  $2\omega$ , adds to the laser hazard (this will always be an Alignment Mode condition). The standard brown goggles protect against both Nd:YAG frequencies.

**5-pass bowtie amplifier (class 4)**

This Ti:Sapp amplifier stage is seeded by the output of the 4-pass and pumped on either side by the PRO lasers. The crystal is AR coated for 532 (partially) and 800 nm (primarily) on both faces. The 800 nm beam makes 5 passes through the crystal at slight horizontal angles, and the pumps enter through the center horizontally, with a slight downward angle ( $\sim 2^\circ$ ). The un-absorbed and reflected pump energy is reflected back into the crystal at either end.

**Vacuum pulse compressor output (class 4)**

The vacuum compressor takes the output of the 5-pass, expanded to 3 inches, and removes the linear chirp, shortening the pulse to 40 fs and increasing the peak power to up to 15 TW. Light is directed into the target area. When a compressed amplified beam is focused into air, white light generation can give rise to a cone of laser light extending across the visible spectrum, much of which is not protected against by goggles. White light generation is always a special Alignment Mode situation.

**In-air pulse compressor (class 4)**

The air compressor is located beside the vacuum compressor chamber and takes as input a fraction of the 5-pass energy, in a  $\sim 1$ -inch beam. The hazards of the in-air compressor are similar to those of the vacuum compressor.

**Quantel brilliant (class 4)**

This flashlamp pumped Nd:YAG laser has a removable frequency doubler module that converts 1064 nm to 532 nm. Most of the unconverted  $1\omega$  light is dumped within the frequency converter module. As this laser is not part of any permanent setup, its location can change, and its use generally constitutes an Alignment Mode status.

**Alignment lasers (class 3B)**

Two CW diode lasers operating at 808 nm are available as alignment lasers. The small laser heads must be well fixed in place before switching on.

**HeNe lasers**

The THOR lab has an assortment of at least 3 class IIIb HeNe lasers operate around 5mW. In many setups the beam is expanded and/or attenuated immediately and the class is reduced to 3R or 2M.

**3.3 Hazard Levels**

The various hazard levels are indicated by an illuminated hazard indicator upon entry of the THOR Laser Lab. This indicator communicates the status of laser operations to those entering the lab, and must accordingly be updated whenever operation modes change.

Visitors and qualified personnel are to wear appropriate goggles and ensure the laser warning light is on the correct setting **at all times**.

Clear communication must be maintained whenever changing hazard levels or unblocking contained laser beams. A sweep of the THOR laser and target areas must be performed so that everyone in these areas is aware of the laser status change.

### 3.3.1 No Hazard

This is indicated by all warning lights on the hazard indicator turned off. In this mode there are no lasers on at all. During this mode the lab may be entered without wearing goggles. It is vital to make sure that all increases in the hazard levels be indicated to avoid personnel walking into a laser-hazard area with no goggles. **Always indicate increasing hazards with the hazard indicator!**

The sign must be **inspected before each use** and maintained in perfect working order. For example, a burned-out bulb might cause somebody to think that there is no hazard, and to walk in while a laser hazard is present.

### 3.3.2 “Oscillator”

This mode is used when only the oscillator is on. **Always enter the laboratory wearing your brown protective laser goggles in this hazard level.** Once one has entered the room and determined that the oscillator is blocked before entering the pulse stretcher, and has an opaque cover on it, one may remove the goggles.

### 3.3.3 “Operation”

This is for use when the laser is in normal operating mode, and there are no new beam hazards, or beam paths unfamiliar to any QLUs. **Always wear your brown protective laser goggles in this hazard level.**

### 3.3.4 “Alignment”

Use when there are new and/or unblocked beam paths, or if laser beam alignment is taking place. When this light is on, those entering the lab put on goggles, enter the lab, stop at the entrance and **immediately ask the laser operator what the beam hazard is.** This will require entry into the lab; therefore under no circumstances will the laser operator risk directing laser beams toward the room entrance. **Always wear your brown protective laser goggles in this hazard level.**

Even if unasked, in this mode, the laser operator will inform those entering of any unusual beam hazards.

The room is not to be left empty in “alignment” mode. **Before leaving the laser lab, the QLUs are to remove the additional hazards and set the hazard level to the appropriate lower level (no hazard, oscillator, or operation).**

### **3.4 Rules for Wearing Goggles**

Each Qualified Laser Person is given their own set of goggles. It is mandatory that the goggles are properly cared for as described in Section 3.1 (page 5) be properly worn in compliance with the description of the Hazard Levels above – at all times. While the goggles afford protection against indirect scattering of the laser light and some specular reflections, it reduces the general visibility of your surroundings. Color contrast can also be completely removed. This often makes it difficult to see instrument readouts and your general surroundings in low-light conditions. Therefore it is tempting to “peek” around the protective plastic of the goggles.

**UNDER NO CIRCUMSTANCES WILL PERSONNEL  
"PEEK" AROUND, UNDER, OR OVER GOGGLES!**

This means no tilting the goggles up or down to see below or above them. This also means wearing the goggles correctly. For example, it is also considered peeking if one wears the goggles low on their nose, in order to peek above them without tilting them down.

The no-peek rule includes times when observing oscilloscopes, computer-screens, or anything else that appears to be far removed from the laser optical chain. If one experiences difficulty observing a laser beam or reading an instrument, find a more experienced laser user to determine a safe method – it is likely that the situation has been encountered before and a solution has already been determined. IR viewers, IR paper, fluorescent paper, cameras and monitors have been made available for viewing the laser beam.

**Noncompliance with the use of goggles in the lab will result in the loss of all lab privileges, and possible immediate termination from the group.**

## **4 Lab Maintenance Operations**

A Responsible Individual (RI) system is in place to maintain safe operation of the laser. RIs have received mentorship training on safe operation of specific parts of the lab. Secondary RIs (SRIs) are undergoing mentorship training from the RI and, depending on their experience, serve as a backup RI.

Changes made to the laser system are performed under the leadership of the appropriate RI or SRI, preferably both. This is to ensure that all known details are considered during the changes, improving the likelihood of safe and successful system operation. In all cases, changes to the laser are logged in the laser maintenance logbook.

Maintenance of the large YAG lasers, Pockels drivers and cells, and some laboratory experimental apparatus require access to high-voltage areas. The buddy system is required for such high-voltage work, as well as specialized UT or home-institution training.

A current list of the RIs and their responsibilities can be found at (login with UTEID and password):

<https://webspace.utexas.edu/acb685/www/Lab Maintenance/RI list.pdf>.

RI duties are described in:

<https://webspace.utexas.edu/acb685/www/Lab Maintenance/RI duties.pdf>

**No operation will inhibit the safe egress of the laboratory in case of a fire.**

## **5 THOR Laser Alignment**

The following procedure is for aligning the entire THOR laser system. Partial operation of the THOR lab may be performed with the appropriate abbreviation of these procedures, but this is only to be done by Qualified Laser Operators. First-time operation of THOR should be performed with an experienced Laser Operator.

### **5.1 Preliminary Checks**

- 5.1.1 Check water coolers to ensure that they are operating properly, and have sufficient water levels.**
- 5.1.2 Check the nitrogen purge system gas level at the cylinder in the back of the lab (>100 psi on right gauge ~3 psi on left gauge) & on small regulator on wall near 220 V power plugs (~.7 psi).**
- 5.1.3 Check the spatial filter vacuum pressure (<50mTorr). Look under the table near the PROs.**
- 5.1.4 Check to make sure there are no obstructions in front of the Spectra Physics Pro YAG lasers or in front of the Big Sky laser.**
- 5.1.5 Check to make sure there are no obstructions in any amplified beam paths except for designated beam dumps, shutters, or appropriate energy meters.**
- 5.1.6 Check to make sure the Pockels cell high-voltage is turned on.**
- 5.1.7 Inspect the condition of the 5-pass Ti:sapphire crystal with a flashlight. Make sure it is free of dust or moisture.**
- 5.1.8 Check the status of the humidity detector. Lower the threshold level and make sure the alarm sounds. Return the threshold to the original level. For more information, see section 6.**

## 5.2 Oscillator Warmup

- 5.2.1 **Make sure there are no ungoggled personnel in the lab and hazard indicator is set to "operation."**
- 5.2.2 Hold down the Laser Power button on the Spectra-Physics Millennia control box until it turns on.
- 5.2.3 Press the top-left button until you get to the setup screen.
- 5.2.4 Press the UP arrow to open the shutter
- 5.2.5 Press the top-left button until you get to the main screen.
- 5.2.6 Set the output power to 4.50 W using the arrow keys, or the P2 button.
- 5.2.7 Block the oscillator output by attaching black aluminum foil to the plastic oscillator enclosure box.
- 5.2.8 Let the laser warm up for at least 15 minutes.
- 5.2.9 Push the silver button on the back of the Femtosource oscillator to try to achieve mode-locking. If it works, you can now start warming up the other lasers. If not, just continue with the following steps.
- 5.2.10 Wait for the oscillator to warm up for at least 1 hour.
- 5.2.11 Place the small Molectron PM500D power meter into the output of the oscillator, and adjust the output coupler to maximize the power reading (should be at least 500mW).
- 5.2.12 Attempt to mode-lock the oscillator. If the oscillator does not mode-lock, see section 7 Ti:Sapphire Oscillator Troubleshooting.
- 5.2.13 Examine the spectrum on the top computer screen in the rack. It should be smooth and broad (~40nm FWHM, centered near 800nm).
- 5.2.14 If there is a spike in the spectrum, VERY SLIGHTLY adjust the cavity tune screw clockwise (the screw closest to the silver button) to remove the spike.

**5.2.15** Carefully re-adjust the output coupler to maximize the output power. If it is below 500 mW go to the Section 7.

**5.2.16** Record the mode-locked power (use the Molectron Power meter) in the chart.

### **5.3 Spectra-Physics Pro YAG Laser Warmup (Long Pulse)**

**5.3.1** For internal Operation set “Source” to “Fixed” and “Mode” to “LP” on the control boxes.

**5.3.2** For pumping the amplifier (Oscillator must be modelocked) set “Source” to “Ext.” and “Mode” to “LP”

**5.3.3** Check to make sure “Osc.” And “Amp” are at “Start”

**5.3.4** Make sure there are no ungoggled personnel in the lab and proper sign setting is indicated.

**5.3.5** Push “Enable” switch. Light above should come on.

**5.3.6** Wait for the lights above “Osc.” and “Amp” to come on. It takes 1 to 5 minutes for PRO 1. PRO2 will turn off if lamps don’t simmer after about 30 secs. If after several tries, the lamps still don’t work, there are several possibilities:

**5.3.6.1** The lamps are old/bad

**5.3.6.2** The cooling water or water filters are dirty and need to be changed

**5.3.6.3** The power supply need maintenance

**5.3.6.4** DO NOT use a Tesla coil to “jump-start” the lamp

**5.3.7** Again make sure the “Operation” light is illuminated, and check to make sure everyone in the lab is wearing brown goggles.

**5.3.8** Turn “Osc.” knob to “10” and then “Amp” knob to “10”

**5.3.9** Log laser use in book.

**5.3.10** Wait 20-30 min for laser to warm up. While this is happening, you can continue to the Big Sky Laser Warmup.



#### **5.4 *Big Sky Laser Warmup***

- 5.4.1 Confirm that the controller is in Configuration #2 (external trigger mode). This is the normal operating mode.**
- 5.4.2 Make sure there are no ungoggled personnel in the lab and proper sign setting is indicated.**
- 5.4.3 Turn on the flash lamps by pressing the button on the controller (top row)**
- 5.4.4 Enter the “flash lamp” menu and scroll down to the “voltage” setting. Set this voltage to what the chart/paper says. (This should only be different from 1100V when the lamp is dying and we are pumping it harder to get more life out of it)**

#### **5.5 *Beam Transport to the Regen***

- 5.5.1 Use the last mirror inside the Oscillator Plexiglas box to center the beam on the 1st iris.**
- 5.5.2 Place the 1/2-wave plate (set at XXX) before the pulse selection Pockels cell**
- 5.5.3 Use the mirror just outside the box to align the beam to the 2nd iris**
- 5.5.4 Repeat the previous 3 steps until both irises are centered**
- 5.5.5 Align the beam through the fiber**
  - 5.5.5.1 Measure the power straight out of the oscillator and before the fiber input with the small Molectron PM500D power meter and record it in the chart.**
  - 5.5.5.2 Place the power meter at the output of the fiber.**
  - 5.5.5.3 Use the mirror just before the fiber input to tweak up the fiber output power.**
  - 5.5.5.4 If the power is low check the alignment into the stretcher and repeat step 5.5.5.3.**

**5.5.5.5** If power is still low, align into the fiber using second to last mirror to walk and then iterate with the last mirror. Be VERY careful not to lose output. Use the Golden Rule: if you lose the light, reverse the last thing you did – do NOT touch any other mirror.

**5.5.5.6** Record power level exiting the fiber in the chart under “fiber output”.

**5.5.5.7** Remove the  $\frac{1}{2}$ -wave plate before the pulse selection Pockels cell

## **5.6** *Aligning the regen*

**5.6.1** On the Big Sky laser, open the shutter using the menu on the controller (press up twice, and hit right). Check path of laser for obstructions. If all is clear, try Q-switching a single shot (bottom row) and watch for fluorescence in the regen Ti:sapphire crystal. If everything is fine turn on the Q-switch using the controller (bottom row).

**5.6.2** Turn up the brightness of the Tektronix 7104 oscilloscope in the rack to observe the regen buildup. DO NOT leave the brightness turned up when you are not using it, as it will deteriorate/damage the scope display. Only turn it on to look at for brief periods.

**5.6.3** Let laser warm up for 15 minutes

**5.6.4** Check the build-up of the regen on the oscilloscope. The peaks should grow and then level off just before the large spike.

**5.6.5** If the build-up does not look satisfactory (see pictures located at the end), go to regen troubleshooting at the end.

**5.6.6** Check beam profile using the software on the bottom computer (Camera 1) by plugging the regen camera cable into the computer camera input BNC.

## **5.7** *4-pass pump and regen energy measurements*

**5.7.1** If everything looks good so far, use the diverging lens with the Moletron EPM1000 Energy meter with the attached white diffusing plate to measure the 4-pass pump energy along the long stretch where it is parallel to the regen box. Be sure to keep the head far enough away from the lens so as not to damage the

energy head, but close enough so that the beam fits on the head (around 6" away or so). Record this value in the chart.

- 5.7.2 Use the same lens and Energy head to measure the regen output (pre-polarizer) just a few inches from where you measured the 4-pass pump energy. Be sure to keep the head far enough away from the lens so as not to damage the energy head, but close enough so that the beam fits on the head (around 6" away or so). Record this value in the chart.
- 5.7.3 Temporarily block the Big Sky beam which pumps the 4-pass. Carefully open up the box where the seed beam goes into the 4-pass box and carefully measure the post-polarizer regen energy right after the polarizer (WITH diverging lens). Record this value in the chart.

## **5.8 *Aligning the 4-pass***

- 5.8.1 Now use the same lens and energy head to record the 4-pass pump energy (take out the panel to the left, and measure the energy along the long stretch. Be sure to keep the head far enough away from the lens so as not to damage the energy head, but close enough so that the beam fits on the head (around 6" away or so). Record this value in the chart.
- 5.8.2 Change the switchbox (or computer input BNC cables) to look at the 4-pass (Camera 2). This is the camera after the 4-pass spatial filter.
- 5.8.3 If the 4-pass needs a slight adjustment, block the pump beam, and check the 2 irises before and after the 1st pass through the crystal. Use the 2 previous mirrors to optimize this alignment. Now recheck the 4-pass output. If it is still low, go to the 4-pass Rebuild Appendix.
- 5.8.4 Insert an ND2 filter after the regen output, but before the 4-pass. This will attenuate the beam so we can use the cross-hairs to align through the spatial filter.
- 5.8.5 Carefully rotate the 1st cross hair into the attenuated beam before the spatial filter.
- 5.8.6 Use the mirror on top of the periscope to align to this crosshair. Use the camera to see the alignment.

- 5.8.7** Carefully rotate the 2nd cross hair into the beam after the spatial filter. Use the mirror just before the spatial filter to align the two cross hairs (view them with the camera). You might need to slightly adjust the spatial filter pin hole. Make sure the beam goes through the center of the pinhole by counting turns on the x and y translations. Don't touch the z.
- 5.8.8** Remove the 1st crosshair.
- 5.8.9** Remove the ND filter after the regen.
- 5.8.10** Use the Energy meter, this time without the diverging lens, and measure the 4-pass output energy after the spatial filter output lens. Record this value in the chart. If it is low, go to the energy troubleshooting section at the end.
- 5.8.11** Turn on a small lamp in the room and turn off the overhead lights to make this next section easier.
- 5.8.12** Confirm that the 2nd cross hair is located in the center of the beam on the camera. You might have to use the magic (View-it) wand to see the beam on the 2nd crosshair correctly. For some reason, the camera tends to show the beam a little bit lopsided.
- 5.8.13** Carefully rotate into the beam the 3rd crosshair (input to 1st pass of the 5-pass, near the long PRO telescope end).
- 5.8.14** Use the magic wand to look at the beam after the 2nd and 4th pass. Use the mirror near the 4-pass camera to adjust the beam until the pattern of the 2nd and 3rd crosshairs is centered and symmetric.
- 5.8.15** Remove the 2nd crosshair.

## **5.9 *Aligning the 5-pass***

- 5.9.1** Now use the mirror right before the 3rd crosshair to steer the beam through the 5-pass. You should be able to look at the 4th pass on the magic wand while adjusting the mirror. Once it is centered and symmetric, remove the 3rd crosshair and check the beam shape after the 5-pass with the magic wand. If it looks fine, you are done.
- 5.9.2** Examine the output of the 5-pass with the View-it wand.

- 5.9.3** Check to see that the diffraction rings are well centered in the beam. If it is not symmetric, make small tweaks to the 1st mirror until it looks good. You can use the 4th crosshair to check the rough alignment. If this does not fix it, goto 5-Pass Rebuild Appendix
- 5.9.4** Now that the amplifiers are aligned, we need to measure and record the energy level at the output of the laser enclosure. Use the same Molelectron EPM1000 energy meter.
- 5.9.5** Place the energy head at the output of the 5-pass box (where it shoots across to the other table). Record the energy on the chart as "5-pass no heat". Remove the energy head.
- 5.9.6** Compare this number with the chart. If the current energy is less than the minimum as stated on the chart, go to the energy troubleshooting section at the end.
- 5.9.7** Make sure that the Pro's are delayed with respect to the seed. To do this, check the timing boxes. On the top right Stanford box, channels B and C correspond to Pro 1 and Pro 2 Q-switch delays. Make sure both of these are  $\geq 1250\text{ns}$ .
- 5.9.8** Visually check the alignment of the Pro's into and out of the 5-pass Ti:Sapphire crystal. Make sure both beams are hitting in the middle of the crystal.
- 5.9.9** Make sure the transmitted part of each beam is hitting the small 1" mirror at each end of the box. This mirror is used to reflect the light back onto the crystal.
- 5.9.10** Make sure the reflected light is centered on the crystal (not off to one side or to the top or bottom). This is not an everyday alignment thing, but should be checked occasionally, especially if the PRO lasers are steered any.
- 5.9.11** Make sure the optics and crystal are clean and free of dirt and dust. Carefully use an air canister to blow off optics that are dirty. If this does not resolve the problem, you can try cleaning the optics with appropriate optical cleaning methods.
- 5.9.12** Block the beam before it goes into the large post 5-pass spatial filter and also before the air compressor spatial filter. Block the beam path into the compressor and air compressor as a backup.

(Failure to block the spatial filters could result in destruction of the pinholes).

**5.9.13 Turn the “Source” knob of both Pro’s to “EXT”.**

**5.9.14 If the PRO timings are set to 1250ns, turn the “Q-switch” knob of both Pro’s to “EXT”. The seed beam will begin to change shape as the thermal lens grows.**

### ***5.10 If aligning both compressors***

**5.10.1 The spatial filter before the air compressor (ACSF) is much less forgiving than the one before the vacuum compressor (VCSF) because of its smaller size. Therefore, before touching any alignment after the 5-pass see if any light is coming out of the ACSF. To do this, run in lowest energy (PROS at 1300ns) and use an infrared sensitive card at the output.**

**5.10.2 If the beam DOES come through, it means the alignment is very close to the previous day so the beam should also be aligned through the VCSF. In this case adjust both pinholes to optimize beam shape (ACSF using a camera with the ND2 in place after the regen) and go to step BB to align vacuum compressor. Afterward, continue here and go to step CC to align air compressor.**

**5.10.3 If it does NOT come through, go to Vacuum Compressor Alignment Section for the vacuum compressor then carry on here for the air compressor.**

### ***5.11 Aligning the Air Compressor***

**5.11.1 Place a screen in front of the 2” gold compressor input mirror (top) and observe with a camera. Block the VCSF. Look at the mirrors after the ACSF with the IR viewer and move the pinhole. If it is not a big tweak, go to step CC.**

**5.11.2 Bring the ACSF to air making sure that the laser table vacuum tubes remain under vacuum. Put the ND2 in the beam after the regen. Place crosshairs before and after the ACSF tube. Take out the pinhole by removing the 2.75” Conflat flange vertically. Use the two input mirrors to the ACSF to align through the center of the crosshairs. Take out the crosshairs, replace the pinhole, and**

evacuate the tubes to <50mTorr. Now, without too much tweaking, the beam should go through the pinhole.

### 5.11.3 CC

5.11.4 Put in the two crosshairs on the input line to the air compressor. Change the PRO timing to get the bright spot in the beam again. Align the first crosshair to the center of the bright part of the beam and overlap the second crosshair.

5.11.5 Change the PROs back to 1300ns (lowest power). Take all crosshairs out and let the beam through the compressor.

### 5.11.6 FF

5.11.7 Use the IR viewer to look at the position of the beams on the two gratings. Make sure the iris of the viewer iris is closed down to avoid being confused by scattered light. Look at the small grating and slowly turn up the power until two spots are clear. The top spot should be directly above the low spot (but they do not necessarily have to be in the center of the grating). On the large grating the beam should form two broad stripes lined up vertically and approximately central horizontally on the grating. The beam should also be approximately central on the input and output gold mirrors. If alignment is slightly off – try steps DD-EE. If it looks far off go to step EE.

### 5.11.8 DD

5.11.9 Put in the two crosshairs after the compressor. Use a camera or orange card to observe the beam after the first crosshair after the compressor. This crosshair is aligned by again judging the center of the beam. The laser must be run close to optimum timing on the PROs for the beam profile to be correct. So go to full power UNLESS this puts more than 100mJ into the air compressor. If it does, mistime the PROs or attenuate until the input energy is  $\leq 100\text{mJ}$ .

### 5.11.10 GG

5.11.11 A very slight tweak of the last dielectric mirror before the air compressor should center the beam on the crosshair. Tweak the first dielectric mirror after the compressor to align the second crosshair.

**5.11.12 Repeat step FF to check the compressor alignment. Vertical alignment is not too important and is also hard to judge. The horizontal is crucial to the compression. If the alignment is still good, you have finished. If step GG has moved the spots on the small grating off horizontally, the compressor will need tweaking with step EE.**

**5.11.13 EE**

**5.11.14 Repeat CC to check the input line. Tweak the upper gold mirror horizontally looking at the small grating and line up the spots. Now align the final two crosshairs using the lower gold mirror (have a helper reach from under the table) and the first dielectric mirror after the compressor. Now minimize the pulse duration using the second order autocorrelator. If the pulse is significantly  $>50\text{fs}$  the compressor needs more careful alignment (should be  $40\text{fs}$  when everything is correct).**

### ***5.12 Aligning the Vacuum Compressor***

**5.12.1 Rotate the 1st crosshair into the beam before the large spatial filter (just after the periscope).**

**5.12.2 Be careful not to let the Q-switched green beam hit your hand, as it will hurt. Check to make sure the spatial filter input is blocked for both the air and vacuum spatial filters. Change the timing on one of the PRO lasers until a bright spot forms in the middle of the beam (don't use too much energy here, or you could damage optics). The center of this may not necessarily be the same as the center of the diffraction ring pattern. Use the last seed mirror in the 5-pass box to steer the beam so that the bright spot is centered on the crosshair. View the beam using the View-it wand.**

**5.12.3 Place the iris (or 2nd crosshair, depending on the current lab status) before the spatial filter into the beam. Adjust the top mirror on the periscope until these 2 crosshairs are aligned.**

**5.12.4 BB**

**5.12.5 Restore the PRO timing to  $1300\text{ns}$  (lowest power). Remove the 1st and 2nd crosshairs. Remove the beam block from the vacuum compressor spatial filter input. Center the pinhole using x and y translations by counting turns. DO NOT adjust the z-axis unless you know what you are doing.**



- 5.12.6** Make sure the input to the vacuum compressor is blocked and the cross-hairs before the spatial filter are out. View the paper blocking the compressor entrance with a camera.
- 5.12.7** Rotate the 3rd and 4th crosshairs (large ones on the path into the compressor) into the beam. Change the PRO timing to get the bright spot in the beam again. Use the 2nd 4" mirror after the spatial filter to adjust the bright central spot of the beam onto the center of the diagonal crosshair image. Use the 4" mirror (just before the 3rd crosshair) to align the beam onto the 4th crosshair. Iterate between these two mirrors.
- 5.12.8** If the final two crosshairs are well overlapped (make sure to get the correct set of intersecting crosshairs) and centered on the beam but the beam looks off-centre in the circle defined by the 3" second lens in the spatial filter (careful not to get confused by the crosshair mounts), tweak the 4" mirror right after the spatial filter. Then repeat step 59.
- 5.12.9** Place a beam block in the target room. Remove all crosshairs. When you are ready to use the laser, rotate the piece of paper out of the way of the compressor entrance. The beam is now compressed, and it is in the target room.
- 5.12.10** Go align the beam to your experiment. Alignment should be done with as little energy as possible (start with B and C > 1250ns).
- 5.12.11** Full energy corresponds to ~ 1140ns on B and ~1120ns on C. If high energy is crucial, you should optimize these PRO timings.

## **6 Humidity Monitoring and Control**

The 5-pass crystal is water cooled to 12 °C. At times the RLM air conditioning fails or otherwise does not remove enough moisture to prohibit water condensation on the crystal. In the past, when this has happened, pumping by the full-power Spectra Pro laser beams has resulted in serious damage to the crystal, as the water droplets acted as tiny lenses, focusing the laser light onto the crystal faces. Replacing or repairing the crystal is expensive and time-consuming. The humidity monitoring and control system is developed to prevent future failures of this sort.

### **6.1 Description of humidity detection**

A small humidity/temperature sensor is housed next to the 5 pass crystal, which sends data (via the serial port) to the computer connected to the lower monitor in the computer

rack. The data acquisition and plotting is performed by a continuously-running LabView program. The LabView program uses this information to calculate vapor pressure in mm of Hg. The critical point at which the cooled crystal will accumulate moisture is ~**13 mm Hg**. We determined that a safe maximum set point value for running the laser is **11 mm Hg**.

## 6.2 Audible Alarm

When the vapor pressure goes above the setpoint value of **11 mm Hg** an audible alarm will sound.

**If the alarm sounds the PRO lasers should be taken out of Q-switch mode, voltages turned to zero, and the RI should be contacted.**

## 6.3 Maintaining Low Humidity at the 5-Pass Amplifier Crystal

There is a small motor under the 5-pass amplifier optical table, which re-circulates air from the black plastic box housing the 5-pass crystal. The air is forced through a canister filled with Drierite, which dries the air.

The humidity from the little amount of air that is passed through the canister is almost entirely removed, so that even the little amount that is forced through acts to substantially reduce the overall humidity of the air in the box. **This system works only when the laser enclosure is closed! Take the Spectra PRO pump lasers out of Q-switched mode when opening up the laser enclosure until it is determined that the laboratory air is not too humid!**

After a while, the Drierite must be replaced with fresh Drierite. The Drierite is color-coded to indicate whether it must be replaced.

Used (wet) Drierite: PINK  
Fresh (dry) Drierite: BLUE

Remove the canister by simply pulling off the air-tubes from the canister, and rotating the canister so that the tube-connectors slip past the mounting rings. Fresh Drierite can be found in jars on top of the flammable cabinet.

## 6.4 Refreshing Drierite

Dry pink Drierite for at least for 2 hours at 200 C in the oven in Keith's lab (setting 4-5). Make a tray using aluminum foil and spread the Drierite flat before baking. After drying, the aluminum foil tray can be formed, making it easy to pour.

## **7 Ti:Sapphire Oscillator Troubleshooting**

This is a work in progress. For now, get the help of a senior graduate student with experience in troubleshooting the oscillator, or the help of Gilliss or Aaron.

## 8 Regen Troubleshooting

- 8.1.1 If the symptom is that the energy meter is reading low, check that it is working correctly and that the entire beam is hitting the active region of the detector head.
- 8.1.2 Make sure the neutral density filter was not inadvertently left in front of the regen output.
- 8.1.3 Make sure the Big Sky pump energy reaching the regen crystal is near-nominal.
- 8.1.4 Check for damage on the various optical elements of the regen cavity, paying particular attention to the thin-film polarizer. An electric IR viewer is handy for this – look for extra scatter off the elements.
- 8.1.5 To optimize the seeding of the regen, slightly tweak the corner mirror before the regen to optimize the buildup (it should shift the peaks to the left of the scope). If this does not fix the problem, go on to energy troubleshooting.
- 8.1.6 Slightly adjust the green pump beam steering into the regen box (it should shift the peaks to the left of the scope). Be careful not to steer the green beam too close to the edge of the crystal, as it will ablate copper onto the crystal face.
- 8.1.7 Look at the spectrum of the regen after the 2nd polarizer. You can scatter the beam off of a piece of paper, and let the fiber pick up the scattered light. If there is spectral modulation, then the regen Pockels cell is either mis-timed, not receiving the appropriate voltage, or is mis-aligned.
- 8.1.8 If you look at the post polarizer output scatter with a photodiode, you should only see 1 peak. If there are post-pulses, then first try to optimize the timing of the Pockels cell – only after writing down the current settings! If that doesn't work some combination of the post regen Pockels cell and the 2 calcite polarizers might need to be tweaked.
- 8.1.9 You can also try dusting off the various optical elements using a gas-duster held upright. This can include the thin-film polarizer, the Ti:sapphire crystal, and the end mirrors. Check for damage again if the energy seems low and nothing else fixes it.

**8.1.10 Do not adjust the end-mirrors of the cavity, the crystal, or the thin-film polarizer without getting a second opinion as a “sanity check.”**

## **9 Energy Troubleshooting**

- 9.1.1 Now that the amplifiers are aligned, we need to measure and record all of the energy levels at different stages in the laser. Use the Molectron energy meter with diffusing plate and the mounted diverging lens**
- 9.1.2 Place the diverging lens in the path of the Big Sky along the side of the regen box. Place the energy head downstream of this lens ~6-12 inches. Make sure the entire beam is hitting the head, and record the energy on the chart as “Regen Pump Energy”. Remove the energy head.**
- 9.1.3 Move the lens (away from the regen) over to the seed beam (regen output). Place the energy head downstream of this lens and record the energy on the chart as “Pre-polarizer energy”. Remove the energy head. Remove the lens.**
- 9.1.4 Remove the top end cover of the 4-pass box. Place the energy head just after the collimation lens of the spatial filter and record the energy on the chart as “4-pass output”. Remove the energy head. Replace the cover.**
- 9.1.5 Compare these numbers with the chart to locate where the problem is. Bear in mind that you should look for semi-dramatic changes in energy indicating damage or gross misalignment. Gradual drops in energy due to aging lamps in pump lasers are expected and don’t need fixing, unless the energy drop is too much.**
- 9.1.6 If none of this fixes the problem, ask around and find someone else to look at the problem. Hopefully they will bring a new perspective to the problem.**