Appendix 1

LASER REGISTRATION FORM (LS-1)

LASER REGISTRATION FORM (LS-1)		**Laser Ref. No:**	CRT/ICL/F11,F12
Policy Note: This form is to be completed, and a copy sent to the Departmental Laser Supervisor, for **all** lasers ***except*** inherently safe Class 1 lasers (e.g. laser printers, CD players etc) and laser pointers below Class 3.			
1. Department			
Department:	Department of Chemistry	**Room Number/ Location:**	ICL, CAESR Labs, F11/F12
Name of Research Supervisor:	Prof. Christiane Timmel	**Name of Departmental Laser Supervisor:**	Dr Lavina Snoek
2. Laser Safety Process			
Process	**Date Completed**	**Research Supervisor Signature**	**Departmental Laser Supervisor Signature**
LS1 Registration	27/01/2026		
LS2 Risk Assessment	27/01/2026		
LS3 Local Rules	27/01/2026		
3. Overview of project, the laser and environment			

Title: Lasers in CAESR EPR Labs (ICL, F11 and F12)

A series of different lasers and laser diodes are available within the CAESR labs for in-situ generation of photoinduced paramagnetic states in the EPR spectrometers. The samples are placed inside a resonator and cryostat and are illuminated with laser pulses or continuous irradiation.
Experiments in the CAESR EPR labs (ICL, F11 and F12) typically use Nd:YAG lasers and/or OPO systems producing laser pulses between 213 nm and 2800 nm. During standard operation, the full laser system is entirely enclosed.

Lasers:
The lab includes multiple laser systems on a fixed optical table and on two mobile laser tables that can be positioned in front of each of the two spectrometers.

An EKSPLA integrated diode-pumped solid-state laser and OPO system can be operated between 210 nm and 2600 nm, through one of three output ports (OPO, OPO/SCU, OPO/SH/SF) with an additional port providing access to the fundamental and the harmonics (1064 nm, 532 nm, 355 nm) and a port for fibre coupling of the OPO.

An OPOTEK Opolette integrated flash-lamp pumped laser and OPO system can be operated between 410 nm and 2200 nm, with one port providing the OPO output (turn for signal/idler) and additional ports for the fundamental and harmonics.

A GWU VersaScan system pumped by a Spectra Physics Quanta Ray laser is mounted on a fixed optical table and provides high energy output at wavelengths from 213 nm to 2800 nm. The pump laser is only accessed and measured during maintenance visits from a laser engineer, and at all other times these laser beams are dumped within the laser in enclosed beam dumps.

Each laser has a dedicated power supply and water-cooling circuit placed under the corresponding laser table (on the mobile laser tables for the EKSPLA and Opolette). The different pieces of equipment for each laser are plugged into a single extension lead that is always plugged into the wall, either in the use position in front of the spectrometers or in the store position in a corner of the room.

LASER REGISTRATION FORM (LS-1)	Laser Ref. No:	CRT/ICL/F11,F12

Beam Delivery:
The laser beams are delivered through-space within fully enclosed systems, with custom optical tables and beam tubes used to cover the beams between laser table and the optical window of the cryostats for EPR. Some applications require excitation with an optical fibre, which is inserted into the sample tube and placed within the sample holder and cryostat for operation.

Laser energies of <4 mJ are typically used whenever the beam leaves the optical table, the laser power is adjusted by setting the Q-switch timing or by placing a half-wave plate and a polarizer at the output of the laser unit to adjust the power.

Routine alignment takes place when a new experiment is started, arranging half-wave plate, polarizer, a series of mirrors and typically a depolarizer on the laser table. An alignment card is placed on the cryostat to ensure the laser beam is in the correct position to excite the sample inside the resonator.

For delivery by optical fibre, the laser beam is focused into the optical fibre on the laser table, and the output power is checked at the fibre end extending through the sample rod mounted firmly on the laser table for this purpose.

Process:
The lasers are used for photoexcitation of a variety of samples within EPR spectrometers for the spectroscopic characterisation of photoinduced states and processes.

Environment:
The lab is split into two parts with separate interlock circuits, which can also be joined if needed. There are two doors allowing entry into the two lab sections, a partition that splits the two labs, a window between the two sections and four windows to the outside. All windows are equipped with laser curtains that are closed during laser operation.

Each of the lasers is fitted with an interlock system linked to the door entry for the section of the lab where it is operated. If the door, any window, or the separation between the two lab sections is opened, laser emission is stopped. Two keypads allow access to the two different lab sections when the lasers are in operation. If the doors remain open for more than 15 seconds, the laser emission is stopped automatically. Each of the lab sections has an emergency stop button that stops the laser and allows opening of the doors. A key switch inside the lab allows deactivation of the outside keypads to prevent users from entering the lab if laser alignment is in progress.

The lasers are bolted onto mobile optical tables that are entirely enclosed with black panels. When in operation, they are placed in front of the electromagnet of the EPR spectrometers and clamped down in a fixed position. A beam tube is placed between laser table and optical window of the cryostat.
The GWU laser is on a fixed optical table in F12, and used either for direct through-space beam delivery through a beam tube and an additional optical setup mounted on the magnet or with an optical fibre.

4. Detail the specifications of all Laser(s) involved in the system:

OPO systems on mobile laser tables

Make:	**EKSPLA**		**Lambda Photometrics OPOTek Opolette**	
Model:	NT230-50-SH/SF-SCU-FC-2H		OPOlette HE355	
Serial no:	#PGD277			
	pump laser	OPO system	pump laser	OPO system
Wavelengths:	1064 nm, 532 nm, 355 nm	210-2600 nm	532 nm, 355 nm	410- 2200 nm
Maximum output power:	148 mJ @1064 nm 53.7 mJ @532 nm 56.2 mJ @355 nm	max ca. 18 mJ @420 nm	15 to 20 mJ at 355 nm	max ca. 8.5 mJ @420 nm
Beam diameter:	5 mm		3.4 mm	
Beam divergence:	0.8 mrad	2 mrad	< 2 mrad	
CW or Pulse repetition rate:	50 Hz		20 Hz	
CW or Pulse length:	2-5 ns		7 ns	
Classification:	4		4	
MPE – Eye	20 mJ m^{-2} @1064 nm (per pulse, 100 s exposure time) 2 mJ m^{-2} @532 nm (per pulse, 100 s exposure time) 6.7 mJ m^{-2} @355 nm (per pulse, 30 ks exposure time)	2 mJ m^{-2} @420 nm (per pulse, 100 s exposure time)	16.7 mJ m^{-2} @355 nm (per pulse, 30 ks exposure time)	2 mJ m^{-2} (per pulse, 100 s exposure time)
MPE – Skin	200 J m^{-2} @1064 nm 40 J m^{-2} @532 nm 200 mJ m^{-2} @355 nm (per pulse)	40 J m^{-2} @420 nm (per pulse)	500 mJ m^{-2} @355 nm (per pulse)	100 J m^{-2} @420 nm (per pulse)
Nominal Ocular Hazard Distance	Exceeds room dimensions (3.8 km, 7.3 km, 4.1 km)	Exceeds room dimensions (1.7 km)	Exceeds room dimensions (616 m)	Exceeds room dimensions (1.16 km)

OPO system on fixed laser table and additional Nd:YAG lasers

Make:	**Quanta Ray Nd:YAG + GWU VersaScan/UVScan (OPO)**		**Continuum Surelite**	**Continuum Minilite**
Model:	Lab-170-30H	Versa Scan	Surelite I	Minilite
Serial no:	4370L	flexiScan UV-L+ S/N 0083 versaScan-ULD S/N 2181 uvScan S/N 687	4453-1	4554 14149 (Triad lab) 15/14832-2
	pump laser	OPO system		
Wavelengths:	1064 nm, 532 nm, 355 nm	213-2800 nm	1064, 532, 355 nm	1064 nm, 532 nm, 266 nm
Maximum output power:	800 mJ @1064 nm 300 mJ @532 nm 196 mJ@ 355 nm	50 mJ @500 nm 10 mJ @400 nm 4 mJ @300 nm	400 mJ @1064 nm 250 mJ @532 nm 100 mJ @ 355 nm	25 mJ @532 nm 4 mJ @266 nm
Beam diameter:	7.9 mm		7 mm	~3 mm
Beam divergence:	0.5 mrad		0.6 mrads	<1 mrad
CW or Pulse repetition rate:	20 Hz		10 Hz	10 Hz
CW or Pulse length:	10 ns @1064 nm 9 ns @532 nm 8 ns@355 nm	6-8 ns	7 ns	5 ns
Classification:	4	4	4	4
MPE – Eye	20 mJ m^{-2} @1064 nm (per pulse, 100 s exposure time) 2 mJ m^{-2} @532 nm (per pulse, 100 s exposure time) 16.7 mJ m^{-2} @355 nm (per pulse, 30 ks exposure time)	0.05 mJ m^{-2} @300 nm (per pulse, 30 ks exposure time) 2 mJ m^{-2} @400-500 nm (per pulse, 100 s exposure time)	20 mJ m^{-2} @1064 nm (per pulse, 100 s exposure time) 2 mJ m^{-2} @532 nm (per pulse, 100 s exposure time) 33.3 mJ m^{-2} @355 nm (per pulse, 30 ks exposure time)	2 mJ m^{-2} @532 nm (per pulse, 100 s exposure time) 0.1 mJ m^{-2} @266 nm (per pulse, 30 ks exposure time)
MPE – Skin	500 J m^{-2} @1064 nm 100 J m^{-2} @532 nm 500 mJ m^{-2} @355 nm (per pulse)	100 J m^{-2} @400-500 nm (per pulse)	1 kJ m^{-2} @1064 nm 200 J m^{-2} @532 nm 1 J m^{-2} @355 nm (per pulse)	0.1 J m^{-2} @266 nm (per pulse) 200 J m^{-2} @532 nm (per pulse)
Nominal Ocular Hazard Distance	Exceeds room dimensions (14.3 km, 27.6 km, 7.7 km)	Exceeds room dimensions (20 km, 5-11.3 km)	Exceeds room dimensions (8.4 km, 21 km, 3.3 km)	Exceeds room dimensions (4 km, 7.1 km)

CW lasers and laser diodes

Make:	**Laser Quantum**	**Roiyhner Laser Technik GmbH**	**CNI MLL532/100 mW**	**IR diode laser**	**IR diode laser**	**NEC Corporation**
Model:	Torus Nd:YAG CW laser	405 nm CW diode laser	Visible diode laser	Thorlabs	CNI MLL-III-1047 500 mW (CW)	HeNe alignment laser
Serial no:	62211	15020243	III-9070430/ Oxford Physics inventory 10012	L1060P100J		1055
Wavelength:	532 nm	405 nm	532 nm	1060 nm	1047 nm	632 nm
Maximum output power:	200 mW	200 mW	100 mW	100 mW	560 mW	5 mW
Beam diameter:	1.7 mm	4 mm	2 mm	~1 mm	2 mm	~2 mm
Beam divergence:	0.5 mrads	0.5 mrad	1.5 mrad	~2 degrees	1.5 mrad	~1 mrad
CW or Pulse repetition rate:	CW	CW	CW to Hz pulse rate	CW to Hz	CW	CW
CW or Pulse length:			1 millisecond to CW	modulated at Hz frequencies		
Classification:	3B	3B	3B	3B	4	3R
MPE – Eye	10 W m^{-2}	1 W m^{-2}	10 W m^{-2}	50 W m^{-2}	49 W m^{-2}	10 W m^{-2}
MPE – Skin	2 kW m^{-2}	2 kW m^{-2}	2 kW m^{-2}	10 kW m^{-2}	9.9 kW m^{-2}	2 kW m^{-2}
Nominal Ocular Hazard Distance	Exceeds room dimensions (315 m)	Exceeds room dimensions (1 km)	Exceeds room dimensions (74 m)	1.4 m	Exceeds room dimensions (78 m)	Exceeds room dimensions (23 m)

Lab arrangement and typical laser setups

The general laboratory layout and typical positions of the laser tables are illustrated in Figure 1 with pictures of the EKSPLA set up in front of the E580 spectrometer in F11 in Figure 2.

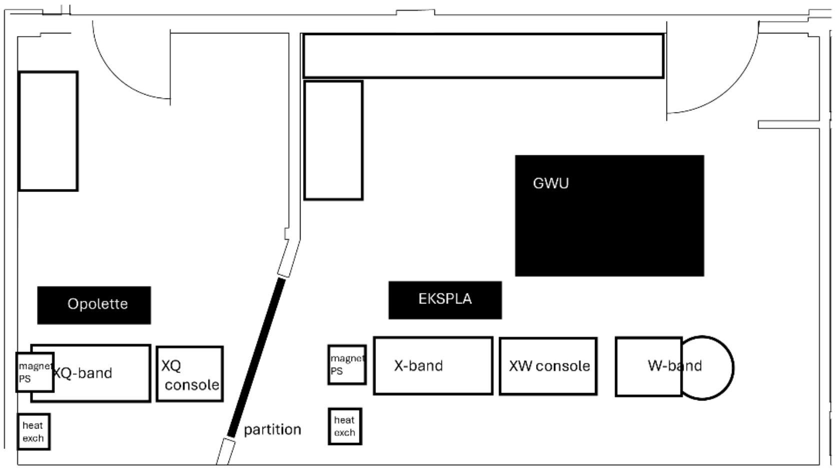


Figure 1. Laboratory layout for CAESR rooms F11 (left) and F12 (right) with typical positions for the two mobile laser tables (EKSPLA and Opolette) and the fixed GWU laser table.

Figure 2. Example of an arrangement of a mobile laser table in front of the E580 spectrometer in F11.

Appendix 2

LASER RISK ASSESSMENT (LS-2)

<table>
<tr><th colspan="4">LASER RISK ASSESSMENT FORM (LS-2)</th><th>Laser Ref. No:</th><th>CRT/ICL/F11,F12</th></tr>
<tr><td colspan="6">Policy Note: A documented risk assessment is required for:
• Use of any class 3R, 3B or 4 laser.
• Any manipulation (e.g. use of magnifying instruments) of a lower-class laser that might increase the risk under certain operating conditions.
• Any lower class laser whose non-beam hazards pose a significant risk, even though the risk from the beam itself is negligible.
• Embedded ‘Class 1 by design’ products encompassing Class 3 or 4 lasers if the beams might be exposed during routine service and maintenance. A contractor’s risk assessment may be sufficient.</td></tr>
<tr><td colspan="6">A copy of this Risk Assessment must be appended to the relevant Laser Registration Form (LS-1)</td></tr>
<tr><td colspan="2">What parts of the life cycle does this risk assessment apply to?</td><td colspan="4"><s>Planning, Design, Manufacture, Testing, Transport,</s> Installation, Commissioning, Normal Operation, Maintenance, Servicing, Modification, <s>Decommissioning, Disposal</s></td></tr>
<tr><td colspan="2">Name of Assessor(s):</td><td colspan="2">Christiane Timmel, Claudia Tait</td><td>Date:</td><td>27/01/2026</td></tr>
<tr><th colspan="2">STEP 1</th><th>STEP 2</th><th colspan="2">STEP 3</th><th>STEP 4</th></tr>
<tr><td>Ref. No:</td><td>List significant hazards</td><td>Affected groups</td><td>List existing controls</td><td>What is the risk?</td><td>Actions required?</td></tr>
<tr><td colspan="6">The lasers:</td></tr>
<tr><td>1</td><td>High Voltage Supply – Possible electric shock in contact with exposed live components</td><td>Research staff</td><td>- no exposed electrical components, access only allowed for experienced personnel
- laser table connected to earth
- equipment regularly electrically tested</td><td>low</td><td></td></tr>
<tr><td>2</td><td>High power beams of pump and OPO lasers within laser systems – possible skin or eye injury from direct exposure</td><td>Research staff

Students</td><td>- laser head covers secure
- access to high power beams within the laser and OPO systems not required except for maintenance by experienced personnel (typically laser engineers from the company supplying the laser)
- laser is key-controlled and lab is interlocked</td><td>low</td><td></td></tr>
<tr><td>3</td><td>Water cooling – possible slip hazard or risk of electrical shock if in contact with electrical components</td><td>Research staff

Students

Support staff</td><td>- system is a closed loop with secure connections and limited amount of water
- system is visually checked for leaks every time it is switched on
- all electrical components are on the laser table, not directly on the floor</td><td>low</td><td></td></tr>
</table>

LASER RISK ASSESSMENT FORM (LS-2)			Laser Ref. No:	CRT/ICL/F11,F12	
4	Trip hazard from cables connecting equipment on laser table to power, interlock and spectrometer	Research staff Students Support staff	- cable management system in place for cables on the laser table to minimise trailing cables - power cord trip hazard protection strips to be used	low	
5	Manual handling – moving mobile laser tables	Research staff Students	- laser tables typically to be moved by two people	low	
Beam delivery:					
6a	Beam delivery from laser system to cryostat or sample rod – possible skin or eye injury from exposure to high powered beam **Normal operation (free-space delivery)**	Research staff Students	- laser table completely enclosed when the laser is running during normal operation - beam tube in place from laser table to cryostat, always in place during normal operation - access to the laboratory is restricted to authorised and trained users only while lasers are in operation - laser shutter closed and/or laser turned off when placing power/energy meter in beam path for power/energy measurements	low	
6b	Beam delivery from laser system to cryostat or sample rod – possible skin or eye injury from exposure to high powered beam **Normal operation (optical fibre delivery)**	Research staff Students	- the sample rod containing the fibre is fixed within the laser table during alignment of the laser into the fibre and energy/power measurement and optimisation - laser only turned on after the sample rod, including sample, has been placed into cryostat and secured - the laser tables are fully enclosed, and the fibre is threaded through a small secure opening on the back panel of the laser table during operation	low	

LASER RISK ASSESSMENT FORM (LS-2)			Laser Ref. No:	CRT/ICL/F11,F12	
6c	Beam delivery from laser system to cryostat or sample rod – possible skin or eye injury from exposure to high powered beam **Alignment of laser beam for experimental setup**	Research staff Students	- alignment is only performed by authorised users, all users in the lab need to be authorised for alignment and aware of the on-going procedure, the interlock is set to alignment mode to prevent people from entering the lab - laser safety goggles to be worn at all times during operation of the laser without top cover on laser tables during alignment - the optics are held in a horizontal plane well below eye-level, no elements with reflective surfaces are used inside the laser table - system designed to always keep beams within the plane of the laser table and below eye level - anodised aluminium side panels on the laser tables always remain in place when the laser is on (users to check they are firmly attached before starting laser operation) - alignment is performed at wavelengths where laser safety goggles provide maximum protection and with the minimum necessary power to observe the laser spot on alignment cards	low	
7	Potential fire hazard associated with beam delivery	Research staff Students Other building occupants	- most experiments do not require laser powers high enough to cause a fire hazard - laser beam dumps to be used to terminate any residual beams inside the laser table - no flammable materials or substances are allowed within the laser table	low	

LASER RISK ASSESSMENT FORM (LS-2)			Laser Ref. No:	CRT/ICL/F11,F12	
The laser process:					
8	Accidental exposure to laser beam during operation if beam tube or side panels are knocked off	Research staff Students Support staff	- side panels firmly secured on laser table and checked before operation - beam tube firmly secured on table and on cryostat, checked before operation - optical fibre firmly secured inside sample rod, laser turned off during insertion and removal of the sample rod - beam tube between main GWU laser table and small additional laser table attached to magnet interlocked to stop laser emission if tube moved out of place - only users with laser training and aware of the different laser setups allowed in the lab during laser operation	low	
Environment:					
9	Possible exposure to laser beams to other users of the room	Research staff Students	- laser curtain between two parts of the room closed if a laser is in operation in one part of the room - laser interlock system prevents entry of not laser-trained users	low	
10	Risks associated with other equipment used in conjunction with lasers	Research staff Students Support staff Visitors	- separate risk assessments to be read and signed by any users of the CAESR labs - extensive training provided prior to independent use of spectrometers and lasers	low	
STEP 5					
Date for review: 31/01/2027					

Appendix 3

LASER LOCAL RULES (LS-3)

LASER LOCAL RULES (LS-3)	Laser Ref. No:	CRT/ICL/F11,F12

Policy Note: Laser Local Rules are required when engineering controls are not adequate to fully control any significant risk from a laser beam.

A copy of these Local Rules must be appended to the relevant Laser Registration Form (LS-1) and Risk Assessment (LS-2)

1. TRAINING REQUIREMENTS FOR AUTHORISED USERS

All persons present during operation of the lasers must be trained as follows:

- Attendance on the 'Introduction to laser safety' seminar by the Departmental Laser Supervisor or University Laser Safety Officer, pass online laser safety assessment.
- Group laser training regarding local rules, protocols and the specific laser systems to be used. This will include:
  - Understanding of every single component, beam path, wavelengths, pulse energies and pulse durations on the laser table
  - General operation of the laser system and accompanying experimental equipment.
  - Understanding of the hazards associated with the laser system.
  - Laser start-up and shutdown procedures.
  - The correct use and limitations of control systems (enclosures, interlocks, warning lights, curtains, ventilation)
  - Selection, use, storage and limitations of personal protective equipment.
  - Supervisory arrangements, specifically any activity that requires close supervision.
  - Entry requirements for non-authorised users into the Laser Controlled Area.
  - Emergency procedures and accident reporting arrangements.

Those persons authorised to use the laser are named and listed in individual Laser User Training Records (LS-4).

2. LASER CONTROLLED AREA

The CAESR laboratories F11 and F12 are defined as a 'laser-controlled area' for the operation of the different lasers listed in the laser registration LS-1 form. Both laboratories are laser-interlocked with Laser Hazard Warning signs at each door. A copy of the laser registration form, risk assessment and local rules are kept in the lab (folder on shelf on the left of the door to F12, copies attached to the wall).

During laser operation, access is restricted to authorised users by the use of a key code entry system. No unauthorised person is permitted into the area, unless:

- Accompanied by an authorised user, under the controls outlined in these local rules
- An authorised user has confirmed that ALL lasers in the laser-controlled area have been switched off and/or all beam shutters have been closed
- In an emergency when the emergency stop button is operated to shut down the lasers.

Individuals working inside the 'Laser Controlled Area' must:

- Follow procedures, instructions and protocols given within these local rules and/or by the supervisor.
- Notify the supervisor if identified controls are not or indeed cannot be followed.
- Notify the supervisor of any significant failure or change to the system.

- Ensure all visitors to the laboratory are appropriately instructed and adhere to the local rules.
- Ensure circulation routes are kept clear of obstacles at all times.
- Ensure work area is routinely inspected and items removed and/or appropriately stored.
- Ensure personal protective equipment is inspected for damage before use and stored correctly.

The Laser Controlled Area is typically operated as two separately interlocked rooms, with the laser partition in place to separate them. Operation as a single jointly interlocked room is allowed if the same user/group operates both spectrometers and if all users are laser-safety trained.

3. PROCEDURES

3.1 General operation

The lasers may only be used if securely mounted inside one of the fixed or mobile laser enclosures (black anodised aluminium side panels and removable lids for alignment purposes). During general operation the lasers and the beam paths are fully enclosed, including a beam tube between laser table and cryostat or a shielded optical fibre between laser table and sample.

Operation of the lasers in the CAESR laboratories requires the following:

- The interlock system including illumination of the warning light at the relevant door is turned on.
- The laser is fully enclosed, including beam tubes and/or optical fibres.
- The door override system (button on the inside, keypad on the outside) is only active when all laser guards and enclosures are in place.
- Laser safety goggles (as specified in section 4.3) must be worn when any of the laser guards and enclosures are removed. All users in the lab should be made aware of the wavelength currently used and of the required type of safety eyewear.
- Jewellery, watches, or other reflective items must be removed to avoid stray beams.
- Seating must be adjusted to make sure eye height is always above the plane of the laser beam.
- Other users wanting to access the laboratory should ring the bell and wait for the laser user to tell them whether it is safe to enter and what laser safety eyewear to wear. If the keypad has been disabled from the inside (red LED next to it turned off), no user should attempt to enter the lab but instead ring the bell and wait for a response.

A separate set of rules for alignment is detailed in the next section (3.2).

Operation of the lasers should be in accordance with the relevant instruction manual, available on the shelf in F12 or on the laser table corresponding to each laser, in the blue cabinet for the Quanta Ray and GWU lasers. Training specific to each laser system will be provided by the supervisor or a designated experienced user and recorded on the training record form. If in doubt, please ask your supervisor or an experienced user.

A brief summary of the general steps to be followed is outlined below:

Turning the laser system on

- Move the laser table to the desired location and clamp it into place. Take care when moving the table, avoid vibrations as much as possible.

  If using the GWU OPO, attach laser table to the magnet and put the beam tube connecting it to the fixed laser table into place.
- Plug in extension cord to power the laser and additional electronics on the laser table, put trip hazard protection strip into place.
- Ground laser table by connecting it to the green/yellow wires available on the GWU table next to the console in F12 and on the wall to the right of the magnet power supply in F11.

- Plug in interlock cables to connection points below the spectrometer table on the E680 and on the wall next to the power supply for the E580. The interlock must be powered off while connecting or disconnecting the plugs.
- Close all window blinds, doors and put the laser partition separating F11 and F12 into place.
- Turn the power to the interlock system on, turn the key to activate the interlock and press 'reset'/'arm laser' on the interlock panel. This permits operation of the laser and the 'DO NOT ENTER' light should illuminate outside the room.
- Turn on the heat exchanger/cooling system of the laser (EKSPLA, OPOTEK Opolette or Quanta Ray/GWU) and check that the water level is in the required range.
- Make sure the required optics for the desired mode of operation are in the correct position, stable and clean. The laser setup should include a half-wave plate and a polarizer to allow attenuation of the laser beam to the power/energy required for the experiment. Neutral density filters are also available as an alternative/additional way of attenuating the laser beams.

  When not in use on a specific laser setup, optics must be stored in their respective boxes and should never be left on the laser table or benches facing upwards as the collected dust will cause degradation of the optics. If any adjustments or changes to the beam path are required, designated users may align the laser following the procedures outlined in the next section.
- Make sure the appropriate laser safety eyewear for the wavelength to be used (see section 4.3 below) is available and completely intact. Laser safety eyewear must be worn any time part of the laser beam is exposed and may only be removed once the laser beam path is entirely enclosed.
- Inspect the laser table and make sure all side panels are fixed securely, the beam tube is secured in place and the lids are closed.
- The laser may then be turned on, with the system fully enclosed. If alignment is necessary, follow the procedure outlined in the next section instead.

Operating the laser and performing experiments

- Laser safety eyewear must be worn at all times if the laser is not fully enclosed (this should only be the case during alignment or minor adjustment of the beam path for signal optimisation).
- Assuming all optical elements are in place for operation, to measure the energy/power, switch the laser off, place the energy/power meter in a post holder placed just before the opening where the beam exits the laser table (check the height using a ruler), close the lid of the laser table and then turn the laser on to measure the energy/power. Switch the laser off before removing the detector. The laser may require some time to warm up before reaching a stable output power. If the power meter is placed in the optical path while the laser is running, wear laser safety eyewear and use a shutter or beam dump to stop the laser beam while putting the detector into position.
- For minor adjustments of the beam path to maximise signal intensity, wearing laser safety eyewear, slowly adjust the last mirror while monitoring the signal intensity. Only remove the lid to expose the part of the table you require access to and make sure to keep hands outside of the beam path. Large deviations from the initially optimised position should be avoided as the cryostat may be damaged.

Turning the laser system off

- Turn the laser emission off, close any shutters on the laser and table.
- Turn the laser off and switch the heat exchanger off.
- Turn the interlock system off.
- Update the laser log book with the relevant information relating to your measurement session.
- If the laser table is moved to a storage position, make sure the extension power cord is plugged in to keep crystals at a constant temperature.

3.2 Routine alignment

Only individuals authorised on the Laser Training Record for alignment are permitted to undertake the procedures summarised below with the following precautions:

- The external keypad must be isolated from within the laboratory using the key switch on the wall to prevent anyone entering the laboratory while alignment is in process and the laser system is not fully enclosed.
- Only authorised users are permitted within the laboratory during alignment and need to be made aware of the procedure. If possible, anyone not involved in the alignment procedure should temporarily leave the lab.
- Only remove the top lids of the laser tables required to access the part of the beam that is being aligned, keep the rest of the enclosure in place so as to limit potential exposure to the beam.
- Ensure the lighting in the room is sufficiently intense.
- Significant changes to the beam path need to be discussed with and authorised by a supervisor.
- Routine alignment does not include opening any of the covers of the lasers themselves.
- **Laser safety eyewear must be worn at all times during alignment**. This includes any users present in the lab while alignment is carried out. Under no circumstances must direct viewing of the laser beam be attempted even if the beam has been attenuated.
- For experiments requiring two lasers operating at different wavelengths, alignment of each laser must be performed separately, wearing appropriate laser safety eyewear. Operation of both lasers is only allowed once the beam path has been enclosed completely.

General procedure for routine alignment (free space beam delivery)

- Before turning the laser on, inspect all the optical elements, make sure they are of the right type for the intended wavelength and power and check that they are clean. Carefully plan out the required beam path, minimising the possibility of stray reflections, ideally following general arrangements outlined in the appendix to the laser registration from. Place all elements into posts at the correct height (using ruler).
- Alignment should only be performed at a wavelength where the available laser safety goggles provide maximum protection (typically 532 nm for operation in the visible range).
- Place the laser power/energy meter directly at the output of the laser system, close the lid and turn the laser on in low-power mode (adjustment mode/Q-switch set to result in low output power – see respective laser manual). Adjust the power to the minimum required to follow the beam with an alignment card.
- Systematically build up the beam path with the required optical elements, checking each one for correct height and position. Any optical elements must be firmly attached to the laser table in the correct position when the laser is on/output shutter open. Take special care when using flip mirrors or magnetic mounts. The laser beam should be blocked before changing the beam path. Use beam dumps as required to avoid stray beams during alignment.
- For free-space beam delivery, initially align the laser within the laser table. With the laser off or shut, remove the beam tube and place the alignment card onto the optical window of the cryostat. Make sure no reflective surfaces are in the beam path (e.g. vacuum pump connections).

  Put the shutter on the laser table output into place and then turn the laser on. Use an alignment card to follow the beam from the table to the cryostat, adjusting the beam position as you go to end up on the desired position on the cryostat.

  It may be beneficial to use an iris to restrict the beam diameter to the size of the inner cryostat window/resonator window.

  Turn the laser off/close the shutter and put the beam tube into place.
- Place the energy/power meter on an optical post just before the laser table opening, place the lid on the laser table, fully enclosing the beam, and set the laser to the desired wavelength and energy/power.

- For fine adjustments based on signal intensity, only remove the minimum possible part of the enclosure and carefully adjust the last mirror while monitoring signal intensity. Laser safety eyewear appropriate for the laser wavelength must be used during this procedure.

Additional considerations for alignment for optical fibre delivery

- Alignment of the laser into optical fibres carries the added danger of light being scattered upwards towards the laser user from the end of the fibre due to the fibre output typically being highly divergent.
- The sample rod or adapter containing the optical fibre must be firmly secured in a mount on the optical table during the alignment procedure.
- The end of the fibre should be inserted into a beam tube followed by the energy/power meter to avoid exposure to scattered light.
- Alignment of the laser onto the fibre chuck is recommended before inserting the fibre and performing fine-adjustments and setting the desired output power.
- The laser should not be turned on unless the optical fibre is mounted on the optical table for alignment or in its final position for measurements.
- While testing the optical fibre output at the desired final power, the full system must be enclosed within one of the laser tables. Check the maximum power allowed for the type of optical fibre used to avoid damage. Consider that beams directed through the optical window of the resonator are typically attenuated, lower powers (<1-2 mJ) are therefore needed for direct beam delivery to the sample with optical fibres.
- During operation, the full beam path on both ends of the optical fibre must be completely enclosed.
- Any exposed part of the fibre must include cladding and reinforced tubing to avoid light scattering in case the optical fibre cracks. Handle the fragile optical fibres carefully to avoid breakage.

Supplementary information on main laser systems

EKSPLA laser and OPO

The EKSPLA NT230 OPO has four exit ports and an additional fibre coupling port. One exit port provides access to the harmonics (1064 nm, 532 nm, 355 nm), the other three exits correspond to different OPO outputs as indicated in Figure 1. All outputs are equipped with mechanical shutters. The laser table has two output ports that allow for different placements of the laser table in front of the E580 and E680 spectrometers. A possible proposed arrangement of the optics and power meter is illustrated in Figure 2. Optical elements for use with the EKSPLA laser are stored in boxes in one of the drawers in F12, elements covering the visible and NIR ranges are available and clearly labelled.

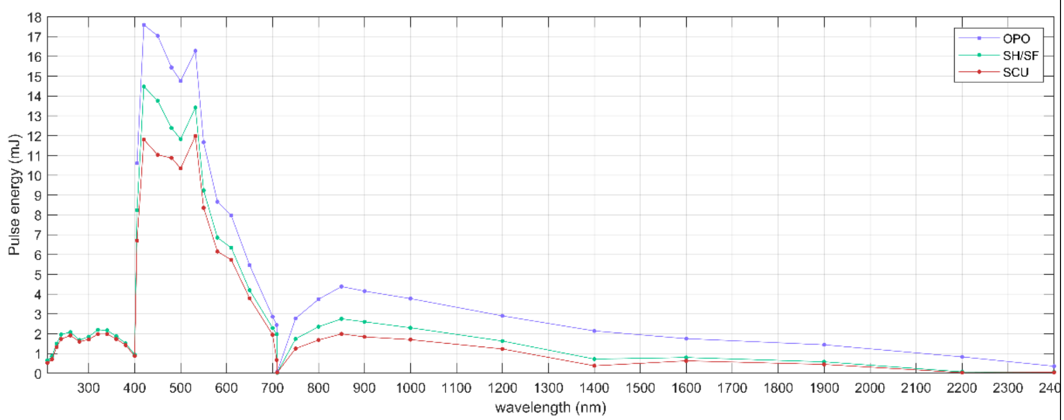


Figure 1. Pulse energy as a function of wavelength for the different output ports of the EKSPLA NT230 laser system.

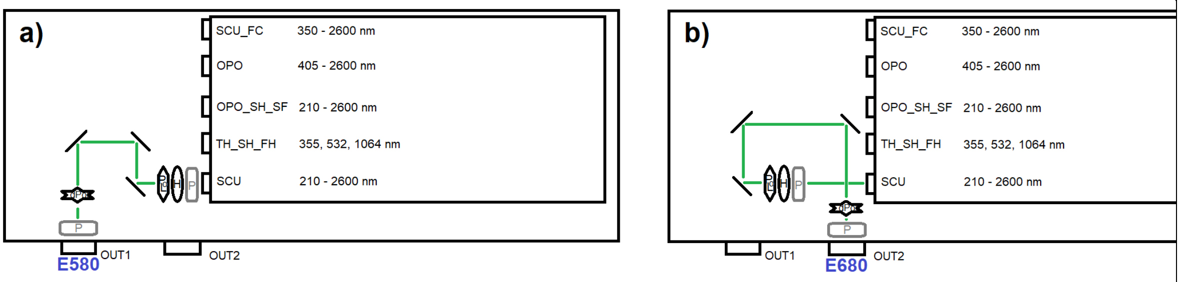


Figure 2. Diagram of one of the proposed free-space beam paths of the Ekspla NT230 for E580 (OUT1) and E680 (OUT2) spectrometers. Panel a) shows the OUT1 path, applicable to the SCU and FH_SH_TH outputs. Panel b) shows the scheme applicable to OUT2 path, except SCU_FC, for going to the E680.

OPOTEK Opolette OPO

The Opolette has three laser exits; one for the actual OPO beam, one for 532 nm and one for 355 nm (see Figure 3). The harmonic shutters are usually covered by screwed-on caps. A setup with a moveable breadboard allows using all three exits with as little alignment as necessary, as optical elements are mounted for the Opolette exit, the 532 nm exit (these two use the same elements) and for the 355 nm exit. The elements are placed such that the same board position works for both the 355 nm and Opolette exit. If the 532 nm exit is wanted, the breadboard needs to be moved. The pathways contain a λ/2 waveplate and a polarizer with which the power of the beam can be adjusted by rotating the λ/2 waveplate. This allows running the laser at optimum Q-switch delay granting better shot-to-shot stability. Before alignment, make sure that the proper mirrors for the intended wavelength/beam path are in the right positions, that the unused exits are blocked, and that no obstacles are in the beam path (specifically remove mirror II of the 355 nm path if using the Opolette exit). The mirrors are labelled with the wavelength range they are suitable for and with their position (I-III) on the board. The mirror mounts are screwed onto magnetic plates and can be pulled off and put back on easily and reproducibly. If required, the lens used is suitable for all wavelengths usually used in the experiment and can stay in place unchanged. Since the mirrors can be put back reproducibly, alignment only requires adjustment of mirror III.

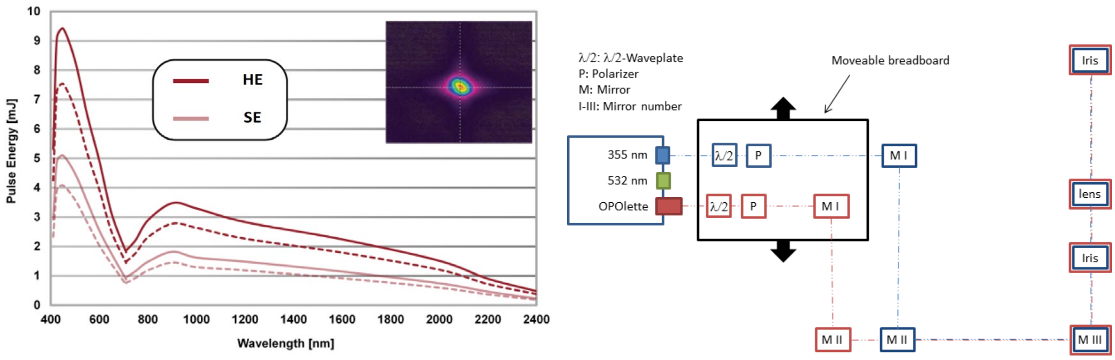


Figure 3. Pulse energy as a function of wavelength for the Opolette HE355 system and beam path and optical setup for OPOTEK Opolette.

Quanta-Ray/GWU OPO

The Quanta Ray and GWU OPO laser and alignment setup is built on a new 2.5 m x 1.6 m large laser optical table, fully enclosed in a purpose-built laser enclosure of aluminium, (non-magnetic) and anodised to absorb scattered light and fitted with internal safety covers which can be removed in sections to allow access to beam steering optics for alignment purposes.

The proposed arrangement for free-space beam delivery from the GWU OPO to the E680 X-band EPR spectrometer is illustrated in Figure 4.

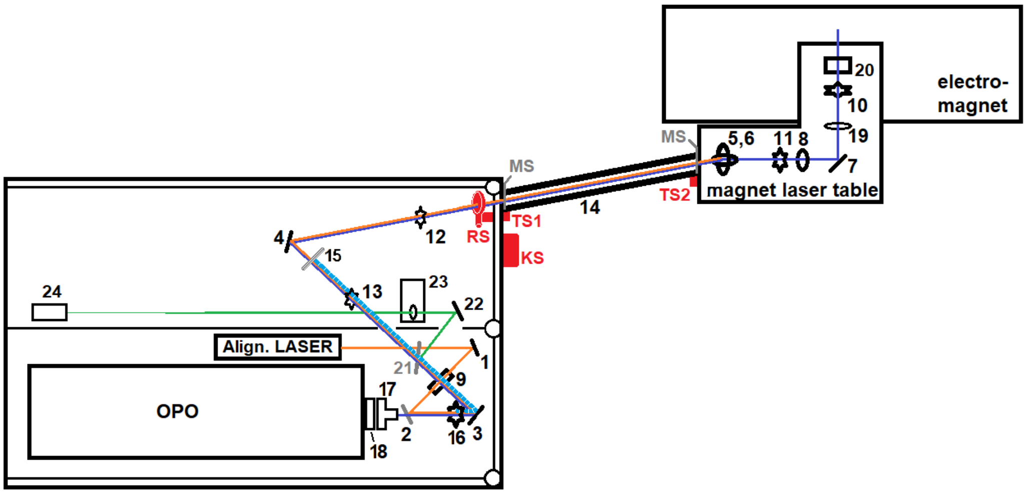


Figure 4. Diagram of free-space beam path from GWU-OPO to electromagnet in ICL room F12. The alignment laser might be class IIIR with safety glasses required. For the local HeNe source, standard amber glasses (LG6) reduce the power to class 2 (0.5 mW).

Numerated Component list:
1-2. First and second alignment mirror, 2 on flip mount, compact 1/2” size and compact mount.
3-4. First and second OPO turning mirror
5-7. OPO turning mirrors (periscope down, periscope across, final mirror to optical window)
8. Broadband depolariser
9. Laser power sensor position
10-13,16. Irises
14. Beam tube enclosure, prepared by workshop
15. far-point alignment, for alignment LASER to be collinear with OPO
17. Glan-Taylor polariser, n.b. variation of this element may cause change beam-pointing.
18. $\lambda/2$ waveplate
19. Focusing optic, optional
20. Final power measurement position.
21-24. Flip-mount mirror to fibre coupling, final mirror for fibre coupling, focussing lens and fibre coupling assembly

Interlock components:
RS. Optical rotary shutter, blocks beam with < 50 ms response time.
TS1, TS2. Tube pressure/limit switch (two positions)
MS. Manual shutters on either end of the beam tube, neither card has an interlock connection.
KS. Key switch bypass

Alignment Procedure:

a) With mirror 2 down, OPO at minimum power (9) gives a target indicated on alignment card (15) using the iris (16). Large wavelength changes or shifting (17) can slightly move the spot. Once a far point OPO spot on (15) is identified, put OPO pump laser in long-pass mode and block OPO output.
b) Using mirrors 1 & 2, the alignment laser is pointed on the indicated spot of card (15), collinear with the OPO.
c) The alignment laser is passed through optimum of iris 12 to mirror 5. If sufficient alignment power is available from alignment wavelength, proceed to align through mirrors 6, 7, and into cryostat, using the irises for beam walking, as necessary. A senior user must attend any KS (key switch) operation. The key will act as a momentary switch, changing the state of the optical rotary shutter (RS), and the key will not be available to general users, who will be able to align independently with a Class 2 alignment laser and demonstrate alignment to a senior laser user before starting experiments.
d) *Note*: Alignment light might not be available for an experiment wavelength, and sequential dichroic mirrors might attenuate alignment lasers too much, such as 266 nm in the UV. In this case, ask a

senior laser user to use the OPO at minimum power to align the laser from mirror 4 to 5, 6, & 7, whilst also using the key switch.

e) Turn-off alignment laser and flip mirror 2 down, enclose table sides and beam tube (14).
f) Check power of OPO output (9) and minimise power using λ/2 waveplate (18).
g) Confirm beam alignment with beam card and make final adjustments if necessary.
h) Open all irises, finish enclosing laser tables, and select operating power (20). Note additional polarisers and optical components may be added to the magnet laser table, after the periscope, as experiments require.
i) Fine-adjust final turning mirror (7), with separate cover, to optimise the EPR signal.

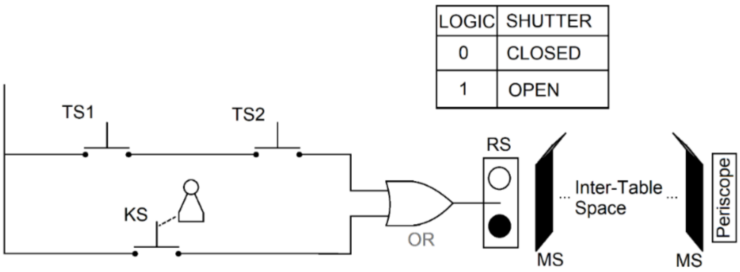


Figure 5. Diagram of beam tube interlock logic and beam path blocks.

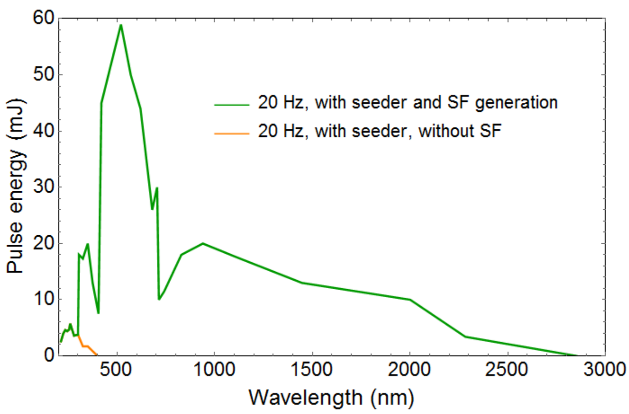


Figure 6. Pulse energy as a function of wavelength for the GWU VersaScan/UVScan system.

3.3 Routine maintenance

Routine maintenance of the laser systems may be performed by experienced users with permission from their supervisors or from the CAESR director (Prof. Christiane Timmel). Any routine maintenance must exactly follow the procedures outlined in the instruction manuals and only be performed by users trained to do so.

Routine maintenance includes:

- Flash lamp replacement (e.g. OPOTEK Opolette, Quanta Ray pump laser for GWU OPO)
- Refilling of the water-cooling system with deionised water
- Exchange of water filters
- Adjustment of the harmonic generation crystals (position (Opolette, Quanta Ray) or temperature (EKSPLA))

3.4 Major alignment and non-routine maintenance

Significant changes in beam delivery need to be discussed with a supervisor and a supervisor, or designated experienced user, must be present during alignment.

Typically, only laser service engineers are permitted to operate the lasers with the laser head cover removed. Under exceptional circumstances, supervisors or designated senior users may perform power measurements and/or major alignment within the laser head if specifically instructed to do so by the support team of the laser manufacturer and only with permission from the CAESR director (Prof. Christiane Timmel).

4. PROTECTION MEASURES – SUMMARY

4.1 Engineering controls

- Lab entry is controlled by keypad access.
- The interlock system is connected to the door, windows and partition separating F11 and F12 and will stop laser emission.
- A laser warning light is active when the interlock system is activated, additional laser warning LEDs are present on the laser controllers and/or the laser head.
- Laser tables with anodised aluminium panels and beam tubes fully enclose the laser beam during normal operation.
- All lasers are securely fixed on a laser table during operation.
- Optics are held in a fixed position on the laser table; the laser beam is always kept on a horizontal plane.
- An emergency stop button is available in each lab to stop the lasers in case of emergency.

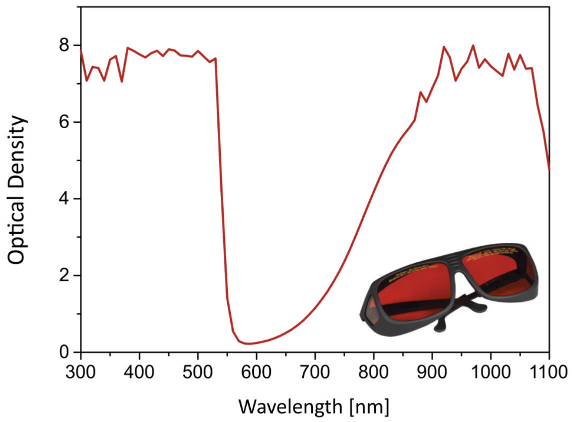
4.2 Administrative controls

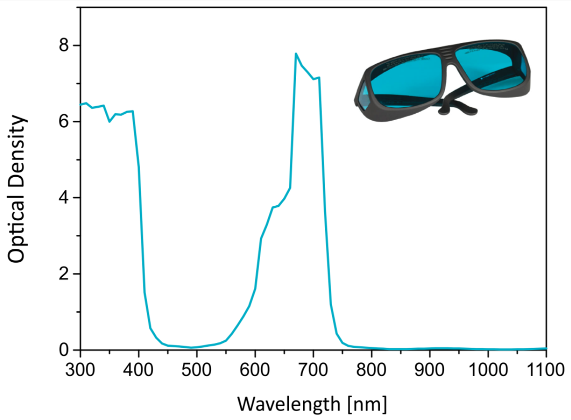
- Only authorised users are permitted to enter the laboratory during laser operation and to operate the lasers.
- Operation is only permitted in accordance with these local rules.

4.3 Personal protective equipment (in addition to normal laboratory procedures)

For the OPO laser systems, the laser safety eyewear should be selected based on the used wavelength. Extra caution is necessary during use of OPOs or laser diodes emitting at wavelengths outside of the visible range to avoid damage induced by these "invisible" beams.

The laser safety eyewear is available in boxes next to the door, with additional safety goggles stored on the shelf in F12. Graphs illustrating the optical density as a function of wavelength are also displayed.





LASER LOCAL RULES (LS-3)	Laser Ref. No:	CRT/ICL/F11,F12

The following protective eyewear is to be used:

Laser	- EKSPLA/OPOTEK Opolette/ GWU OPO in **<=534 nm** and **750 nm to 1085 nm range** - all Nd:YAG pump lasers at **355 nm, 532 nm and 1064 nm** - IR diode lasers - diode lasers at <=532 nm	- EKSPLA/OPOTEK Opolette/ GWU OPO in **540 nm to 750 nm range**
Goggles Make/Model	Thorlabs LG10 (35% visible transmission)	Thorlabs LG7 (35% visible transmission)
General eyewear - EN207 L scale	180 to 315 nm (D LB7 + R LB4) >315 to 534 nm (D LB5 + IRM LB6) 850 to 925 nm (DIRM LB5) >925 to 980 nm (D LB5 + IRM LB6) >980 to 1064 nm (D LB6 + IRM LB7) >1064 to 1085 nm (DIRM LB5 S)	180 to 315 nm (D LB6 + R LB4) >315 to 400 nm (DR LB4) >615 to 660 nm (DIR LB3) >660 to 665 nm (DIR LB4) >665 to 715 nm (D LB4 + IR LB5) 694 nm (IR LB7 S)
Make/Model		

Laser	- EKSPLA/OPOTEK Opolette/ GWU OPO in **<=534 nm** and **750 nm to 1085 nm range** - all Nd:YAG pump lasers at **355 nm, 532 nm and 1064 nm** - IR diode lasers - diode lasers at <=532 nm	
Goggles Make/Model	Glendale Spectra Physics G70111 (14% visible transmission)	NoIR DBY-39 (35% visible transmission)
General eyewear - EN207 L scale	180-315 nm (D L7 + IR L4) 315-532 nm (DIR L6) 800-1080 nm (D L5) 800-850 nm (IR L5) 850-950 nm (IR L6) 950-1080 nm (IR L7)	180-315 D LB7 + R LB4 >315-534 D LB5 + IRM LB6 850-925 DIRM LB5 >925-980 D LB5 + IRM LB6 >980-1064 D LB6 + IRM LB7 >1064-1085 DIRM LB5 S
Make/Model	 This model of safety goggles is completely enclosed and therefore provides added safety during alignment.	

Laser	- EKSPLA/OPOTEK Opolette/ GWU OPO in **>1085 nm range**
Goggles Make/Model	LaserVision R14T1P04L (4% visible transmission)
General eyewear - EN207 L scale	180 – 315 nm (D LB10 + IR LB5 + M LB6Y) >315 – 535 nm (DI LB7 + R LB8 + M LB9) 680 - <690 nm (D LB6 + IRM LB7) 690 - <750 nm (D LB7 + IRM LB8) 750 – 1400 nm (D LB7 + IM LB9 + R LB8) >1400 - <3000 nm (D LB5 + IM LB5Y + R LB4) 3000 – 25000 nm (D LB5 + I LB5Y + M LB6Y)
Make/Model	

4.4 Monitoring

- Users to conduct a visual check of enclosures, warning lights, interlocks, and protective equipment before use.
- Users to check that all relevant optical equipment (e.g. optics, beam stops) are in position before operation.
- Supervisors to check and record each year that the interlock systems are functioning correctly and that the warning lights, LED, signage and labels are operational and/or in place.
- Supervisors to conduct an annual review of the system, risk assessment, local rules and training records.

5. EMERGENCY PLAN

- In case of emergency, all beams must be safely isolated or the power to the laser switched off using the emergency stop by the exit doors or the mains switch.
- The laboratory may be accessed in an emergency via the break glass point located next to the keypad. The laser power is automatically switched off when the break glass point is used.
- In addition to the beam, all other potential hazards must be made safe, electrical supply (as necessary).
- First Aid assistance must be obtained for anyone who is injured. If a Laser eye strike is suspected, the person must be sent to the John Radcliffe Eye Hospital:

  Eye Casualty, John Radcliffe Hospital, Oxford. Tel: 01865 234800.
- The hospital should, ideally, be notified before the person arrives.
- A copy of the laser registration form (LS-1) must be taken with the individual, to help the hospital assess the injury.
- Following any laser injury, the departmental laser safety officer, University Occupational Health Service and Safety Office must be contacted and/or an accident form submitted. This must be done as soon as possible or at least within 24hrs. Once the area has been made safe, the state of the room should be maintained, in case a follow-up inspection is required.