Optical Parametric Oscillator

Levante Emerald

User Manual

Manual of Levante Emerald

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IMPORTANT – READ CAREFULLY BEFORE USE – KEEP FOR FUTURE REFERENCE

This manual contains user information for the Levante Emerald . Read this manual carefully before operating the device. The Levante Emerald has only to be used as described in this manual. Differing use may endanger safety and voids warranty.

CAUTION - USE OF CONTROLS, ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION EXPOSURE!

Symbols Used in This Manual

This symbol is intended to alert the operator to the danger of exposure to hazardous visible and invisible laser radiation.

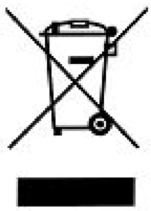
This symbol is intended to emphasize the presence of important operating instructions.

Warranty

The warranty conditions are specified in the sales contract. Any unauthorized modification of the **Levante Emerald** system components or software will void the guarantee and service contract.

Disposal Hints

All electrical and electronic products should be disposed separately from the standard municipal waste system. Proper disposal of your old appliance prevents potential negative consequences for the environment and human health.



Some components of your **Levante Emerald** system are marked with the crossed-out wheeled bin symbol covered by the European Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) of the European Parliament and the Council of January 27, 2003. These items must be disposed via designated collection facilities appointed by government or local authorities.

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1. Introduction

The APE **Levante Emerald** is an Optical Parametric Oscillator synchronously pumped by modelocked frequency doubled Nd:VAN or Ytterbium fiber laser. It is based on collinear, type I non critical phase-matched parametric interaction in LBO in combination with a ring cavity that is resonant for the OPO signal.

The **Levante Emerald** is designed for a highly efficient frequency conversion from 532 nm (Nd:VAN) to 690 ... 990 nm or from 515 nm (Yb-fiber) to 640 ... 960 nm (signal) and ~ 1150 ... 2300 nm (idler). The wavelength tuning mechanism is based on a rough selection of the wavelength via temperature phase-matching in the LBO and fine selection via Lyot-filter and cavity length. It generates trains of picosecond pulses depending on the pump laser pulse duration.
Since this process is jitter free it is very convenient for two colour experiments such as pump and probe measurements. Signal and idler are leaving the OPO resonator from the same output port. Thus, signal and idler are perfectly overlapped in space and time, perfect also for CARS microscopy. Optionally, with the use of dichroic beam splitters as output windows signal and idler can be separated to exit through different output ports. Further wavelength extension into the visible and mid-infrared region by means of harmonic generation of and difference frequency mixing between Signal and Idler respectively is available.

Figure 1.1 shows the optical unit of the **Levante Emerald** OPO from a perspective where the pump input port is visible.

Figure 1.1.: OPO optical unit: Perspective view from the front side.

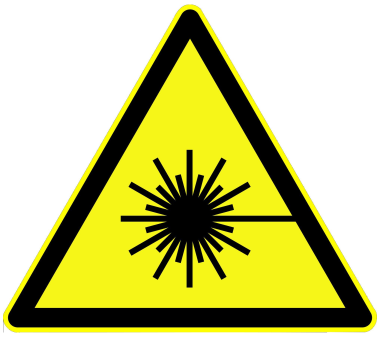
2. Safety Instructions

2.1. Safety Features and Compliance to Government Requirements

US government requirements are contained in 21 CFR, Subchapter J, Part II administered by the Center for Devices and Radiological Health (CDRH).
The European Community requirements for product safety are specified in the "Low Voltage Directive" (2006/95/EC). The "Low Voltage Directive" requires that electronic products comply with the standard EN61010-1:2010 "Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use".
Compliance of this product is certified by the CE mark.

2.2. Optical Safety

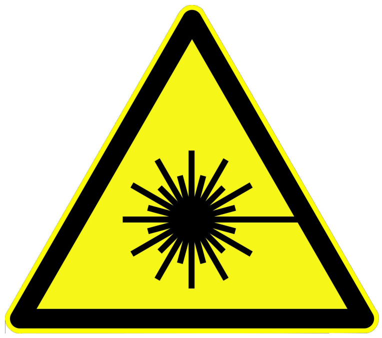
Because of its special properties, laser light poses safety hazards not associated with light from conventional sources. The safe use of lasers requires that all laser users – and everyone else near the laser system - are aware of the dangers involved. The safe use of the laser depends upon the user becoming familiar with the instrument and the properties of intense and coherent beams of light.



Direct eye contact with the output beam of a laser will cause serious damage and possible blindness.
The greatest concern when using laser equipment is eye safety. In addition to the main beam there are often many smaller beams present at various angles near the laser system.
These beams are formed by specular reflections of the main beam at polished surfaces such as lenses and beam splitters. Although weaker than the main beam, such beams

may still be sufficiently intense to cause eye damage. Laser beams are powerful enough to burn skin, clothing, or paint. They can ignite volatile substances such as alcohol, gasoline, ether, and other solvents, and can damage light-sensitive elements in video cameras, photomultipliers, and photodiodes.
The laser beam can ignite substances in its path, even at a distance. The beam may also cause damage if contacted indirectly from reflective surfaces. For these and other reasons, the user is advised to follow the precautions below:

1. Observe all safety precautions in the user manual.
2. Extreme caution should be exercised when using solvents in the area of the laser.
3. Limit access to the laser to qualified users who are familiar with laser safety practices and who are aware of the dangers involved.
4. Never look directly into the laser light source or at scattered laser light from any reflective surface. Never sight down the beam into the source.
5. Maintain experimental setups at low heights to prevent inadvertent beam-eye contact at eye level.
6. As a precaution against accidental exposure to the output beam or its reflection, those using the system should wear safety glasses as required by the wavelength being generated.



Laser safety glasses can present a hazard as well as a benefit; while they protect the eye from potentially damaging exposure, they block light at the laser wavelengths, which prevents the user from seeing the beam. The user should therefore use extreme caution even when using safety glasses.

7. Avoid direct exposure to the laser light. The intensity of the beam can easily cause flesh burns or ignite clothing.
8. Use the laser in an enclosed room. Laser light will remain collimated over long distances and therefore presents a potential hazard if not confined.
9. Post warning signs in the area of the laser beam to alert those present.
10. Advise all those using the laser of these precautions. It is good practice to operate the laser in a room with controlled and restricted access.

2.3. Electrical Safety

The **OPO** uses DC voltages in the OPO head. All units are designed to be operated with protective covers in place. The device complies with protection Class I / EN 61140:2007, degree of protection IP20, according to EN 60529:2010. Certain procedures in this manual require removal of the protective covers. These procedures are normally used by a qualified trained service personnel. Safety information contained in the procedures must be strictly observed by anyone using the procedures.

2.4. Electromagnetic Compatibility

The European requirements for Electromagnetic Compliance (EMC) are specified in the EMC Directive 2004/108/EC. Conformance (EMC) is achieved through compliance with the harmonized standards EN 61000. The device meets the emission requirements for Class A, Group 1 as specified in EN 55011 (05/2010).

Compliance of this OPO with the (EMC) requirements is certified by the CE mark.

2.5. Laser Pump Source

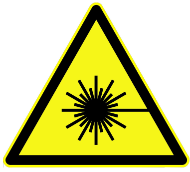
Observe all safety precautions associated with the pump laser. Refer to the pump laser operator's manual for additional safety precautions.

The governmental standards and requirements specify that the laser must be classified according to the output power or energy, and the laser wavelength. The **OPO** is classified to emit laser radiation Class 4 based on 21 CFR, Subchapter J, Part II, Section 1040-10(d) dependent upon the pump laser.

According to the European Community standards, the **OPO** is classified to emit laser radiation Class 4 based on EN 60825-1, Clause 9 dependent upon the pump laser. In the manual and other documentation of the **OPO**, the classification will be referred to as Class 4.

2.6. Protective Housing

The OPO head is enclosed in a protective housing that prevents human access to radiation in excess of the limits of Class 1 radiation, which is dependent upon the pump laser, as specified in the Federal Register, July 31, 1975, Part II, Section 1040.10(f)(1) and Table 1-A/EN 60825-1, Clause 4.2 except for the output beam, which is laser radiation Class 4 dependent upon the pump laser.



Use of controls or adjustments or performance of procedures other than those specified in the manual may result in hazardous radiation exposure. Use of the system in a manner other than that described herein may impair the protection provided by the system.

2.7. Pump Shutter and Shutter Circuit

To prevent the user from accidental exposure to radiation generated within the OPO, the optical unit of the **Levante Emerald** is equipped with an interlock functionality. In contrast to most laser systems that have an interlock-controlled beam shutter at the output laser port, the OPO is equipped with a laser shutter directly behind the input port and the diagnostic electronics of the pump laser beam. This pump shutter can only be opened via the OPO software if the shutter circuit is closed. The pump shutter is closed or cannot be opened in case of the following reasons.:

- OPO power is off
- Shutter connector is unplugged
- Connected shutter is triggered (open shutter circuit)
- One or both OPO covers are detached or removed (open shutter circuit)

Note that this shutter does not fulfill the requirements of an interlock controlled laser safety shutter! Light can still be emitted out of the OPO even when OPO software is not running any more or USB connection to the controller PC is lost!

Take care: Always block the input pump beam in front of the OPO (or close the pump laser shutter if existent) if OPO pump-in shutter is closed!
Long term exposure of the OPO pump-in shutter to pump power levels > 10 W can lead to damage and malfunction of the shutter!

The items related to the shutter circuit will be described in the following.

2.7.1. Shutter Plug

The electronic controller board of the OPO provides a shutter connector at the exit side of the OPO, see Figure 2.1. It has to be connected to the laboratory interlock circuit or bypassed with the delivered jumper plug. The pin assignment of the shutter connector is depicted in 2.2.

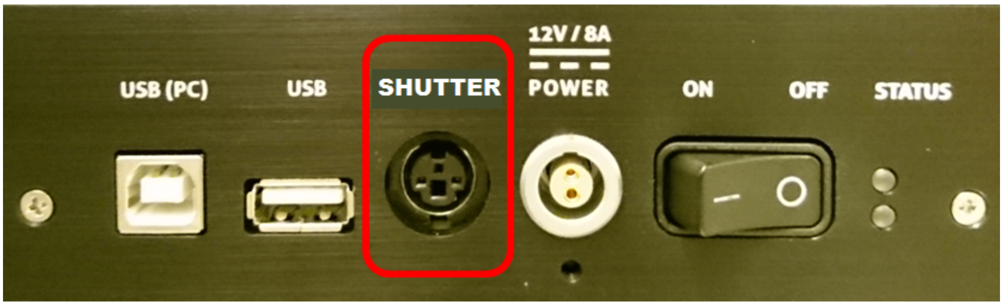


Figure 2.1.: Position of the shutter connector on the electronic board at the exit side of the OPO.

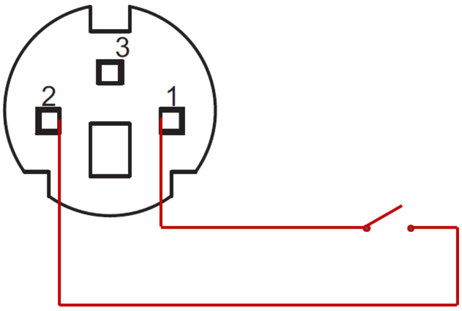


Figure 2.2.: Pin assignment of the shutter connector on the electronic board at the exit side of the OPO.

2.7.2. Shutter Switches

To prevent unwanted exposure to the light generated within the optical unit the position of the OPO covers is detected by two switches (one for each cover). When a cover is removed the respective switch opens the shutter circuit and the pump shutter closes. These switches are located on top of the side wall of the optical unit opposing the internal spectrometer. To enable alignment and installation the switches can be pulled out. This will close the shutter circuit again and allows to open the pump shutter. The three possible positions of the shutter switches are shown in Figure 2.3.

2.8. Location of Safety Labels

As soon as the pump shutter is open laser radiation might exit the OPO optical ports even if the output port shutters are closed. There is also the possibility of back reflected light emitted through the pump beam input port at the front side of the OPO. Also, if a cover is removed the operator might be exposed to collateral radiation. To inform the operator about the possible radiation the OPO covers and all three exit ports are clearly labeled (See figure 2.4).

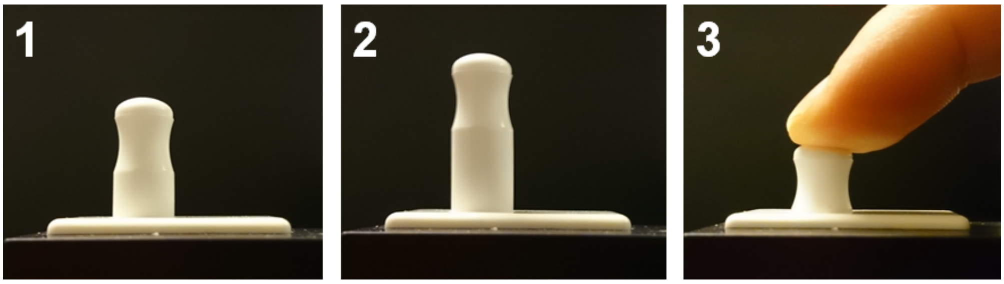


Figure 2.3.: Different positions of the shutter switch; 1- cover removed (shutter will not open), 2- shutter switch pulled out (for alignment), 3- cover in place

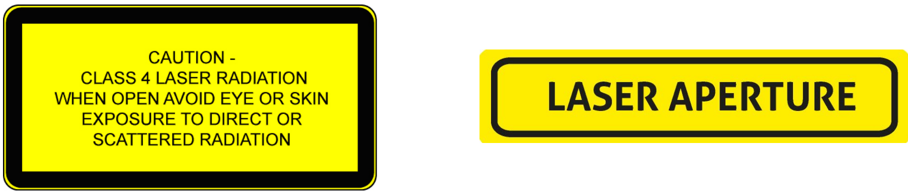


Figure 2.4.: Warning labels at the OPO covers and above the exit ports of OPO.

The OPO is designed to be used with closed covers. These covers shield the operator from all collateral radiation. During initial alignment and maintenance operations, such as cleaning and change of optics, mirror alignment or - in some cases - change of OPO configuration, it will be necessary to remove the covers. The covers are not interlocked with the circuitry of the pumping laser.

Operation of the OPO with covers removed will allow access to hazardous visible and invisible radiation. Act with extreme caution in operating the OPO with covers removed. There might be reflections with high power that may exit at unpredictable angles out of the OPO optical unit. These beams have sufficient energy to cause permanent eye damage or blindness.

3. Description

The **Levante Emerald** consists of the optical unit including pump beam focussing, a ring OPO-cavity, motorized actuator modules (for the shutters, Lyot-angle selection and cavity length adjustment), a crystal heater module and diagnostics for pump and signal power detection. An internal spectrometer (APE waveScan) measures the signal spectrum. Both information, the signal power and center wavelength are necessary for signal wavelength tuning and feed back stabilization of the cavity length. All functionality is controlled with a software running on the provided Notebook. Figure 3.1 shows the outer dimensions of the optical unit. A scheme of the 8 mirror cavity is depicted in figure 3.2. Behind the output coupler (CM2) for both, signal and idler, a lens for re-collimation, a dichroic separator to remove the green pump radiation and a beam splitter for the diagnostics is placed. Behind this, co-propagating signal and idler can be blocked by a motorized shutter or exit collinear through a Brewster window. In case a signal / idler separator is installed instead of the Brewster window (See section 3.4), the signal beam is split-off and reflected to exit through the middle output port. For a detailed description please refer to chapter 5.

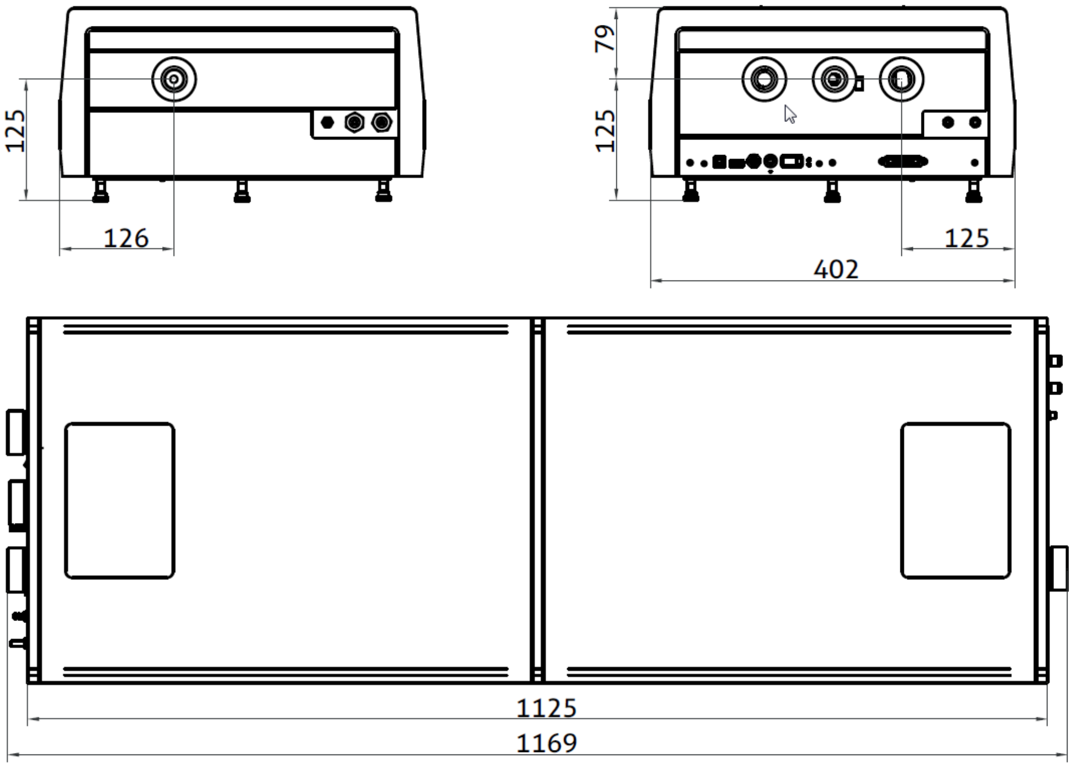


Figure 3.1.: Dimensions of the **Levante Emerald** OPO optical unit

The whole unit is sealed with pump input, signal and idler output windows and two lids to allow purging with dry air or nitrogen. Purging increases the OPO power by maximum 10% in the range from 900 nm to 960 nm. In all other wavelength ranges purging does not have any effect.The purging input connector can be found at the pump-in front side (See figure 3.3). Each lid of the OPO is matched to cover one distinct half of the optical unit.

Do not interchange the lids of the OPO or change its orientation! Always make sure that labeling of the mirror access ports of the lids corresponds to the respective mirror (M1 or M4) at the covered side of the optical unit.

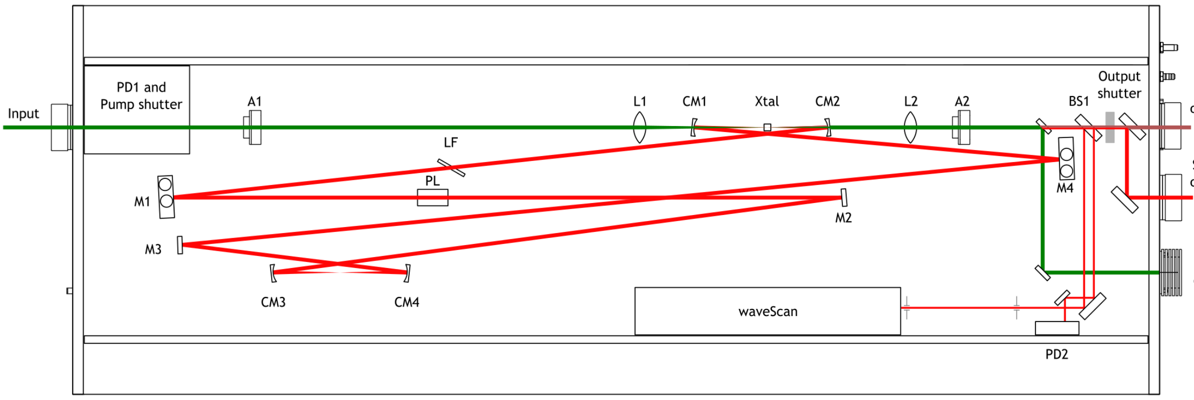


Figure 3.2.: Top view of the **Levante Emerald** OPO optical unit

3.1. Specifications

The **Levante Emerald** OPO platform is flexible to work with different pump parameter settings. It can be configured to accept pump wavelengths between 515 nm and 532 nm, pump pulse durations ranging from 2 ps up to approximately 15 ps and input pump power levels between 2 W and 20 W.
The following specifications are given:

- Repetition rate: equal to pump laser repetition rate (typically around 76 MHz to 80 MHz)
- Polarization (pump in): vertical
- Polarization (signal and idler out): horizontal
- Spatial mode: TEM 00, M^2(signal)< 1.1, M^2(idler)< 1.2
- Noise (rms): $< 1\%$ (limited by pump laser and mechanical stability)
- Time-bandwidth-product: typ. 0.6

Pump laser parameters	516 nm, 3 W, ~ 2 ps [1]	532 nm, 4 W, ~ 6 ps	532 nm, > 20 W, ~ 15 ps [2]
Wavelength range (Signal)	640 … 960 nm	690 … 990 nm	690 … 990 nm
Wavelength range (Idler)	1120 … 2300 nm	1150 … 2300 nm	1150 … 2300 nm
Automated tuning range (Signal)	660 … 950 nm	720 … 990 nm	720 … 990 nm
Output power (Signal)	> 0.7 W @ 800 nm	> 0.9 W @ 800 nm	> 6 W @ 800 nm
Output power (Idler)	> 0.4 W @ 1250 nm	> 0.6 W @ 1250 nm	> 3.5 W @ 1250 nm
Pulse width	$\sim$ 2 ps	$\sim$ 5 … 6 ps	$\sim$ 12 … 15 ps
Spectral bandwidth (Signal)	< 1 nm	typ. 0.3 … 0.4 nm	< 0.1 nm
Photon energy difference			
Signal - Idler	1440 … 9000 cm^{-1}	1440 … 10000 cm^{-1}	1440 … 10000 cm^{-1}
Signal - Laser Fundamental [3]	720 … 5900 cm^{-1}	700 … 10000 cm^{-1}	
Computer interface	Software Interface (using TCP/IP)		

Table 3.1.: **Levante Emerald** specifications

	Operational voltage	Max. input current	Max. power consumption	Dimensions, L x W x H	Weight
OPO head	12 VDC, Power supply: 100 - 240 VAC, 50 - 60 Hz	8 A Power supply: 1.3 A	80 W	1169 mm x 402 mm x 204 mm	90 kg
Controller PC	20 VDC, Power supply: 100 - 240 VAC, 50 - 60 Hz	3.25 A Power supply: 1.7 A	65 W	330 mm x 250 mm x 25 mm	2 kg

Table 3.2.: Dimensions, Weight and Electrical Connection Data of OPO and Ancillary Equipment

[1] APE Emerald Engine, based on NKT aeroPULSE
[2] Coherent PALADIN Advanced 532-20000
[3] When fundamental beam (1032 nm or 1064 nm respectively) is available from pump laser.

3.2. Environmental Conditions

The **Levante Emerald** is intended for operation in indoor, dry and dust reduced rooms. It has to be firmly installed on an optical table or on a similar solid, vibration-free board. During storage, transport, for the installation and during operation, the ambient conditions must be observed. Ensure reasonable transport conditions, free of major shocks, jolt or fall; protect against frost. Use original packing material for relocation. Before unpacking the laser wait for at least 12 hours to allow for acclimatization of all components.

Ambient temperature during transportation and storage if system is switched off:	+5 ... +50 °C
Relative humidity during transportation and storage if system is switched off (mains switch and chiller):	10 % ... 80 % no condensation

If the Levante Emerald has been stored above +30 °C and / or above a humidity of 60 %, please establish environmental operation conditions for at least 12 hours before starting the Levante Emerald .
If the system has been stored for more than two weeks in the above conditions, please allow at least 24 hours in environmental operations conditions before starting the Levante Emerald .

Ambient temperature during operation or stand by (i.e. mains switch on):	+15 ... +25 °C
Relative humidity during operation or stand by (i.e. mains switch on):	< 60 %

3.3. Connectors and Cabeling

All connectors of the OPO are easily accessible at the front and back side of the housing. The connectors for purging can be found at the input side (N2-connection, see Figure 3.3).

Figure 3.3.: Front side of the OPO with the pump input port and the N2-purge connection.

Figure 3.4.: Back side of the OPO with the signal and idler output ports and the electronic connectors at the bottom. If the Brewster output window is installed in front of the right port signal and idler beams exit there collinearly. In case the signal/idler separation optics are installed the signal beam exits from the middle and the idler beam from the right output port.

To operate the OPO it is necessary to connect the power and to have the power button switched on. It is also required to have an USB-connection to a computer running the **Levante Emerald** software and the interlock circuit has to be closed. Otherwise the pump-shutter cannot be opened (See Fig. 3.5). Also, during a safety time of two minutes after power is switched on the pump shutter cannot be opened either.

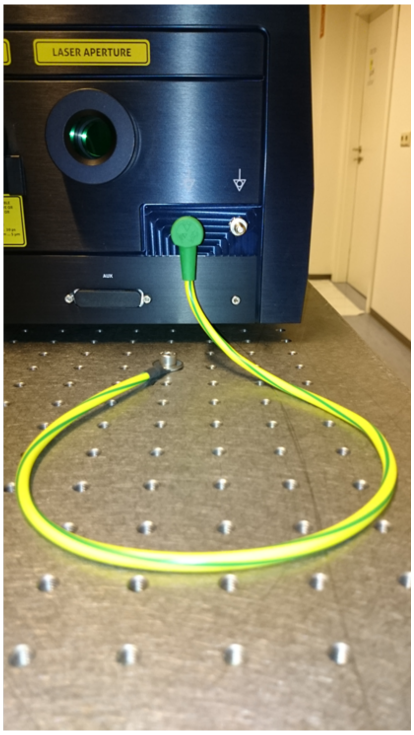


Figure 3.5.: Connections to the OPO output side shown with the delivered cables: USB(PC) - connection to the computer, USB - input connection to the internal HUB (not used), INTERLOCK - connection to the interlock circuit of the lab (shown here: bridged by the delivered jumper), POWER: connection to the power supply, ON-OFF switch, STATUS - green status lamp, grounding of the optical unit.

Take care: **Always leave the optical unit with power on if the OPO-crystal is installed. Even if the software is switched off the heater is hold at a standby temperature of 100 °C to protect the strongly hygroscopic LBO material from humidity. Otherwise, store the crystal in a drying chamber for protection.**

Take care: **Always block the input pump beam in front of the OPO (or close the pump laser shutter if existent) if OPO pump-in shutter is closed!**
Long term exposure of the OPO pump-in shutter to pump power levels > 10 W can lead to damage and malfunction of the shutter!

3.4. Signal / Idler separation

In the Levante Emerald signal and idler are coupled out from the same mirror. Some applications request signal and idler pulses being spatially and temporally overlapped. Others need spatial separation of signal and idler. Therefore the system is delivered with an optional internal signal / idler beam splitter. To change the configuration, please proceed as follows:

1. Block the green input laser beam.
2. Unscrew the black ring from the right beam exit port on the outside of the optics box.
3. Use a hex key to take out the two screws while holding the output window. Exchange it with the Brewster window for non-separated signal and idler or the 45° long pass filter for signal/idler separation, see figure 3.6.
4. For signal / idler separation: The signal beam is reflected by the long pass filter and leaves the optical unit through the central output window. The idler is transmitted through the filter and thus does not change the output port.

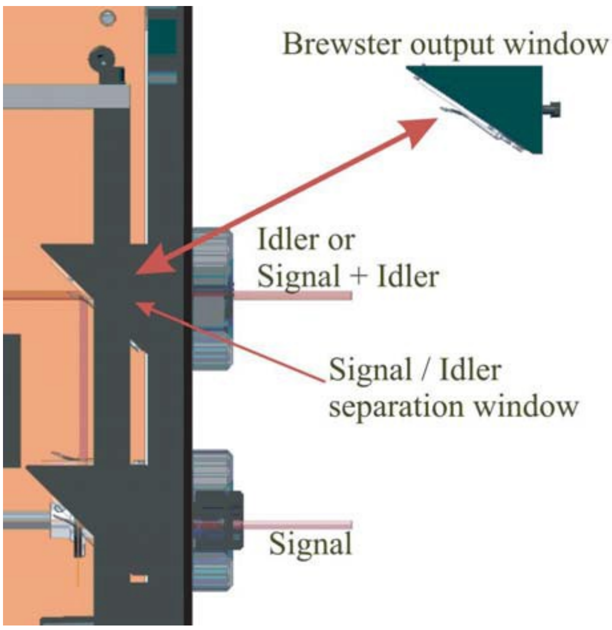


Figure 3.6.: Layout with signal/idler separation window installed and Brewster output window for signal/idler collinear output

4. Software

The OPO software comes pre-installed on a notebook. You will find a shortcut to start the software on the desktop. Alternatively the executable can be found under: C:Program Files\APE\Levante Emerald NSP\Levante Emerald NSP.exe.

4.1. Software Start

Before starting the OPO software please make sure:

- Power is supplied to the OPO optical unit and the unit is switched on.
- The controller PC is connected to the optical unit via USB.
- The interlock circuit is closed, please refer to Section 2.7.

Start the software by double clicking on the Levante Emerald NSP.exe icon on the desktop.
The software opens a window with the request to select a configuration file that corresponds to the current OPO setup:

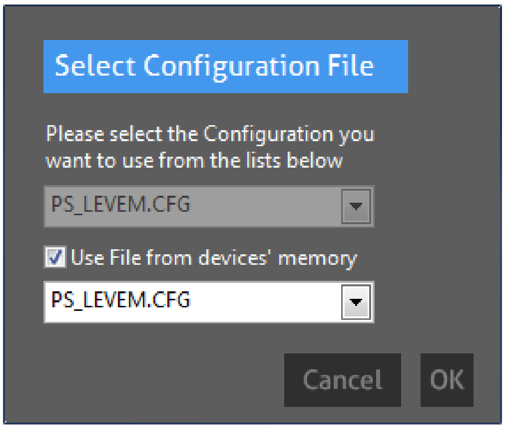


Figure 4.1.: Selection window for the configuration file. This file has to correspond to the actual OPO setup configuration.

The upper drop down menu in Figure 4.1 gives access to the configuration file that is stored on the controller PC at the location:

"C:\Users\Public\Documents\APE\LevEm_OPO\config\PS_LEVEM.cfg".

If the software is stopped at the end changes in the used file are saved only on the controller PC and the local copy is overwritten.

It is recommended to work with this configuration file on the controller PC and to keep the original configuration file that is stored in the EEPROM of the optical unit as a backup.

The lower selection can be activated by setting a check mark in the "Use file from the device's memory" check box. In this case the configuration file stored in the EEPROM of the optical unit is loaded and compared with a copy on the controller PC located at:

"C:\Users\Public\Documents\APE\LevEm_OPO\config\dev\PS_LEVEM.cfg".

If both files are identical the software starts without any further prompt. If the files differ the software shows a selection window, as seen in Figure 4.2.

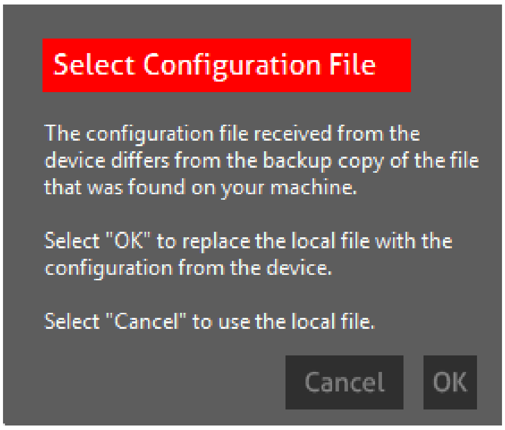


Figure 4.2.: Selection window for the configuration file in case the local reference copy on the controller PC differs from the file saved in the optical unit

To use the configuration file from the EEPROM of the optical unit press "OK". To start the software with the copy on the controller PC press "Cancel". Both files should always be identical because both are duplicates saved when the software is stopped. They can only differ in the following cases:

- cfg-file stored in the optical head is damaged, e.g. due to an interrupt of the writing procedure during software stop. This can happen if the user unplugs the USB cable or the power is disconnected while the software is shutting down.
- If the controller PC is replaced.
- If the local copy on the controller PC was changed manually.

If the second and third case can be ruled out press the ”Cancel” button (see Figure 4.2), else the working copy on the PC will be overwritten.

After choosing the configuration the software starts an initialization routine and opens the software GUI with the ”Manual” mode enabled, as shown in Figure 4.3.

4.2. GUI - Control Elements

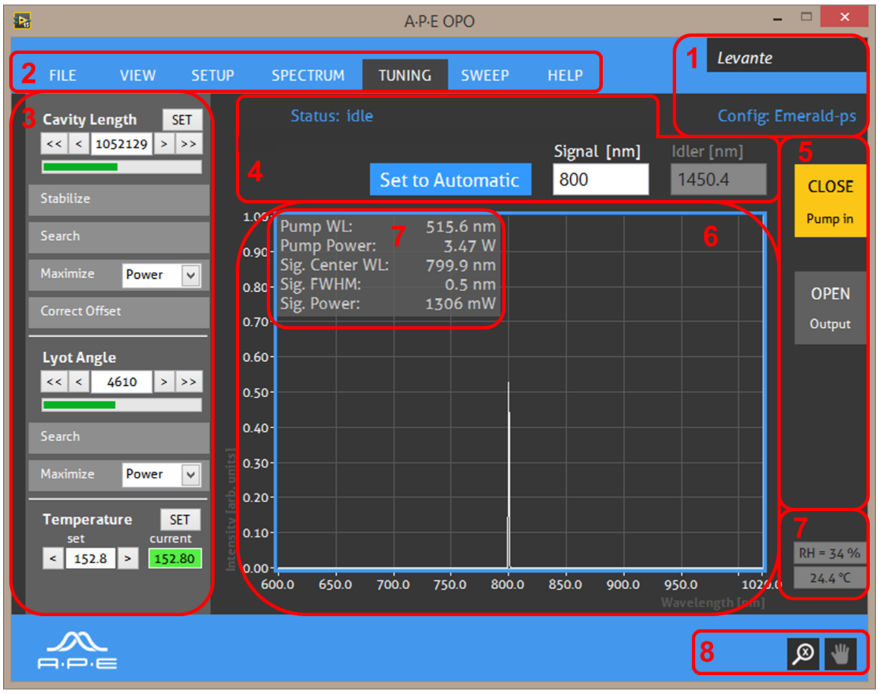


Figure 4.3.: Screenshot of the **Levante Emerald** OPO GUI in the manual mode. 1: Information on the OPO and configuration type; 2: Menu bar; 3: Menu section; 4: Status and tuning section; 5: Shutter controls; 6: Spectrometer display; 7: Information on measured values; 8: Tools for spectrometer display

Figure 4.3 shows the Graphic User Interface (GUI) of the **Levante Emerald** OPO software in "Manual" tuning mode. The pump beam shutter is open ("yellow" warning color), pump beam, cavity and the diagnostic part are properly aligned to generate and detect a signal around 800 nm.
The GUI is arranged in 8 segments. In the following we will describe the functions of the shown controls:

1. **Info section**
   OPO name (Levante) and loaded configuration type (i.e. Config: Emerald-ps) are displayed.

2. **Menu bar**
   After choosing one of the menu options (FILE, VIEW, SETUP, SPECTRUM, TUNING, SWEEP, HELP) the corresponding "Menu section" (3) is displayed. The currently active menu option is highlighted in black. To hide the menu section of a certain menu option click again on the black highlighted option of the menu bar. In the example, see Figure 4.3, the TUNING menu is active that is set by default if no other option is chosen.

3. **Menu section**
   The menu section displays the functions corresponding to the chosen option of the menu bar. If no menu option is chosen the "TUNING" menu section is displayed as shown in Figure 4.3. It shows the actuator controls and buttons of the functional routines for manual signal tuning. This menu can be set to permanent visibility (visible also in "Automatic" tuning mode) by setting a check mark at "Show Actuators" in the VIEW menu. The specific functions of the various menu sections are described in Section 4.3.

4. **Status and tuning section**
   In this part of the GUI the current status of the OPO (e.g. "tuning" or "idle") is displayed. A list of important status information messages is listed in the Appendix A.2. The "Tuning mode" button is used to switch between the "Manual" and "Automatic" state of the OPO. If the OPO is in manual mode the button is blue and shows "Set to Automatic". By pressing this button the OPO software switches to automatic tuning mode. In this state the "Tuning mode" button turns red and shows "Set to Manual". There are two input controls for target center wavelengths of the tuning routine: Signal [nm] and Idler [nm]. Only one of the input controls can be activated by mouse click and set to white. The other is disabled and greyed to serve as indicator of the corresponding calculated wavelength. For example, the Idler wavelength will be automatically calculated for a given Signal wavelength and vice versa.

5. **Shutter controls**
   In this part of the GUI the shutter buttons are placed to monitor and change the state of each shutter. Yellow color indicates an open shutter.

   - **Pump in:** Interlock shutter for the pump beam at the entrance of the OPO. **Note that the button operates the interlock shutter of the OPO. If it is closed no laser light can exit the device.**

Take care: Always block the input pump beam in front of the OPO (or close the pump laser shutter if existent) if OPO pump-in shutter is closed!
Long term exposure of the OPO pump-in shutter to pump power levels > 10 W can lead to damage and malfunction of the shutter!

   - **Output:** Servo shutter in front of the exit port of signal and idler. Independent whether signal and idler are split to exit through different output ports or not, this shutter always opens and closes both channels!

   The "pump in" shutter can only be opened after an initialization period of 120 seconds following the power on of the OPO. In order to use this button no interlock may be activated (i.e. interlock circuit is closed or delivered jumper is plugged in and both covers are completely closed or the related cheat interlock switch is pulled out in case the lid is removed).

6. **Spectrometer display**
   The spectrum of the OPO Signal measured by the internal spectrometer is depicted in this graph. Additional functions of the internal spectrometer and the spectral measurement can be found in the ”Spectrum” menu section (see Section 4.3.4).

7. **Information window**
   The info window displays e.g. measured values of the pump and signal radiation. The position of the info window inside the spectrometer display can be changed by left mouse click and dragging. It can also be edited in the VIEW menu and by right mouse click on the info window.

8. **Tools for the spectrometer display**
   These tools enable digital wavelength zoom (without an increase in resolution) or moving of the shown spectrum. The zoom can be reversed by double left mouse click on the magnifying glass symbol.

4.3. Menus

By clicking on a menu option in the upper menu bar the respective menu section opens on the left hand side of the GUI and the spectrometer display is downsized. The currently active menu option is highlighted in black. To remove the menu section click again on the menu option that is highlighted. In "Manual" tuning mode the TUNING menu is displayed as the default menu in case no further menu option is activated.

4.3.1. The FILE Menu

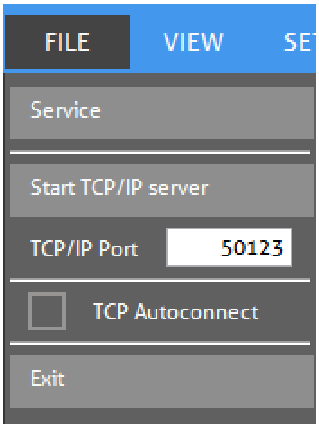


Figure 4.4.: Menu of the activated FILE section

- **Service**: Pressing this button opens an input field for the service password. After entering the correct password the additional menu item "SERVICE" appears in GUI section number 2 (see Figure 4.3). This menu should only be accessed and used by trained personnel for service needs.
- **Start / Stop TCP/IP Server**: For remote control a variety of functions of the software can be addressed via TCP/IP commands (see Appendix A.1). To enable remote control the desired valid port number (1 ... 65535) must be entered at "TCP/IP port". The TCP/IP server has to be started by pressing the "Start TCP/IP server" button. If TCP Autoconnect check box is enabled the server starts automatically with the OPO software.
- **Exit**: Exits the software.

Wait until the software is shut down completely before powering off the OPO, unplugging USB, or shutting down the computer! Otherwise, configuration files might be corrupted due to interrupted saving procedure.

4.3.2. The VIEW Menu

The VIEW menu contains all customizable options related to the appearance of the GUI, the controls and the info text as well as the display of the spectrum.

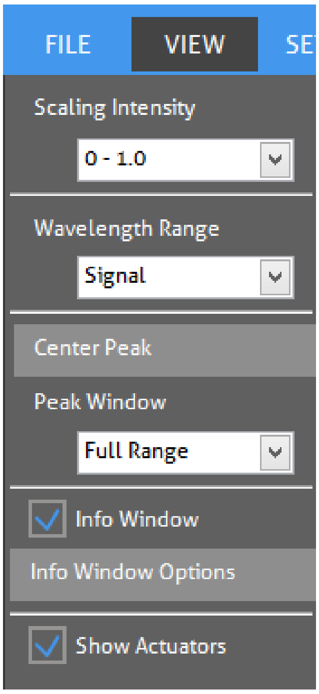


Figure 4.5.: Menu of the activated VIEW section

- **Scaling Intensity**: The intensity axis of the graph can be scaled in 5 variants (0 – 1.0 / 0 – 0.5 / 0 – 0.2 / autoscale / logarithmic scale).
- **Wavelength Range**: The wavelength axis of the graph can be chosen to show
  - Signal range: 600 nm ... 1020 nm
  - Full range: 500 nm ... 1060 nm
- **Center Peak**: A detected spectral peak is centered in the chosen peak window. The center of the displayed window is marked by a vertical cursor.
- **Peak Window**: The peak window is a zoom window with adapted spectral resolution, centered around the peak position of the spectrum. The following wavelength ranges can be selected:
  - ”Full Range”: Displays the measurement range as defined by the above ”Wavelength Range” selector (spectral resolution: approx. 0.4 nm for Signal and approx. 0.6 nm for ”Wavelength Range” set to full range).
  - 200 nm / 100 nm / 50 nm / 20 nm (resolution 0.2 nm)

  The selection of the ”Peak Window” influences the displayed spectral resolution of the graph. By pressing the ”Center Peak” button the spectral signal peak is centered within the ”Peak Window”. The spectral position of this window can be shifted step wise with the arrow software buttons that appear at the bottom of the GUI (see Figure 4.6).

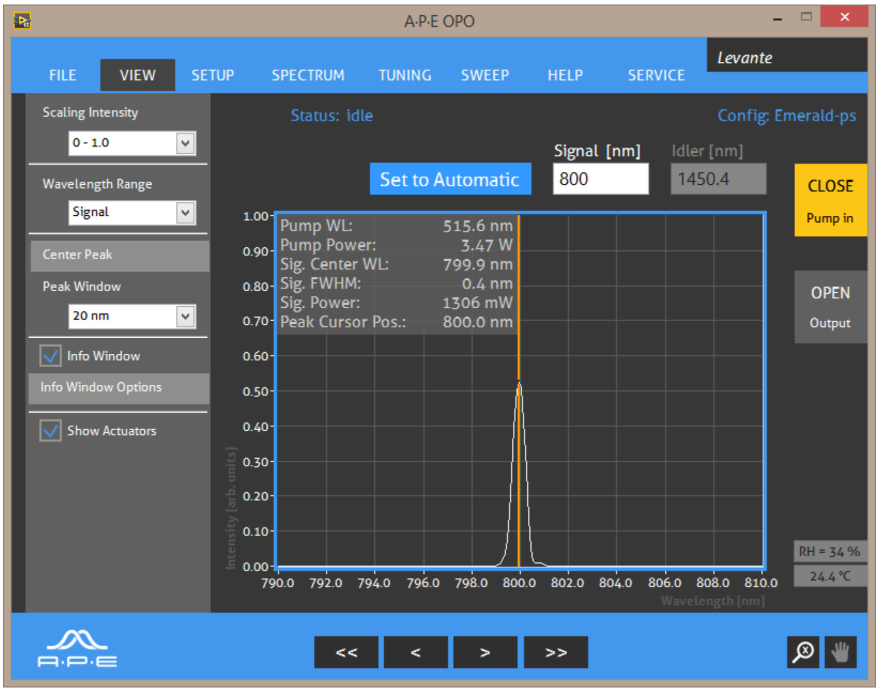


Figure 4.6.: Peak window is set to range of 20 nm around the signal peak. The arrow buttons below the spectrum graph can be used to shift this window step wise along the wavelength axis.

- **Info Window**: By setting a check mark a configurable window appears within the graph to display important measured values (e.g. pump laser and OPO Signal parameters).

- **Info Window Options**: Opens a configuration menu for the info window that gives access to further sub-menus to select or deselect the various parameters (see Figure 4.7). Alternatively, the info window within the spectrometer graph can also be configured via right mouse click on this info window.

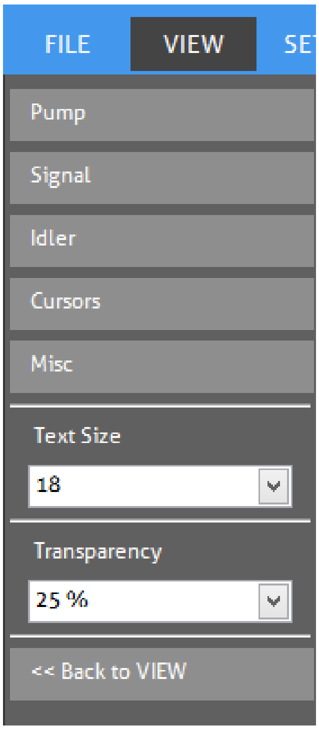


Figure 4.7.: Menu of the info window options that is accessible in the VIEW menu. Alternatively, the info window can be edited by right mouse click on the info window via the appearing drop down menu.

- **Show Actuators**: If this check mark is set the default TUNING menu (see figure 4.10) is displayed also in the Automatic tuning mode and allows to monitor real time actuator positions and states of the automatic routines.

4.3.3. The SETUP Menu

In the SETUP menu the pump laser parameters and custom cavity stabilization tolerance can be set as well as calibration correction of the measured power values is possible.

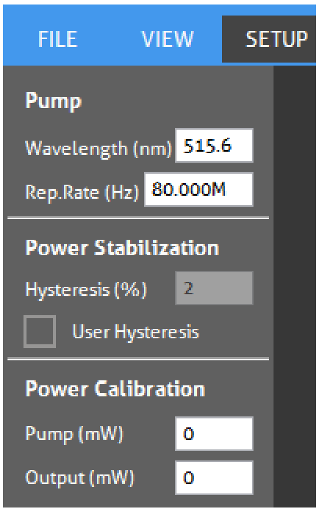


Figure 4.8.: Menu of the activated SETUP section

- **Pump Wavelength (nm)**: The center wavelength of the pump laser in nm is displayed. The depicted value is loaded from the configuration file and is used to calculate the idler wavelength. If necessary, a corrected value can be inserted and is saved.
- **Pump Rep.Rate (Hz)**: The repetition rate of the pump laser in Hz is displayed. The depicted value is loaded from the configuration file and is used to calculate the M2 slider position (refer to figure 4.13). If necessary, a corrected value can be inserted and is saved.
- **Power Stabilization**: Thermal drifts of the pump laser and of the OPO can result in signal power drop. If the tuning mode is set to "Automatic" and the tuning procedure to the set wavelength is finished a cavity stabilization routine adapts the cavity length to hold the initial signal power level. In case the "Automatic" tuning is off the stabilization with the current "Power Stabilization" parameters can be started by pressing the STABILIZE button of the TUNING section (refer to figure 4.10). The cavity length is only actively corrected via the actuator if the measured Signal power drops below a certain tolerance (%) with respect to the initially achieved power (maximum power - hysteresis).

  User Hysteresis: Set a check mark to use a custom tolerance for stabilization.

  Hysteresis [%]: Displays the applied tolerance for stabilization. If "User Hysteresis" is checked the hysteresis control is enabled for a custom input value.

- **Power Calibration**: The integrated power sensors for the pump laser beam and the OPO Signal are wavelength calibrated to display absolute values (mW) in the info window. However, the user can recalibrate the sensors with respect to the currently used alignment and power meter. For this an external measured power value can be inserted in the ”Pump (mW)” and/or ”Output (mW)” controls respectively. The ”Output (mW)” control corrects the displayed Signal power value.

4.3.4. The SPECTRUM Menu

The SPECTRUM menu contains all relevant functions of the internal spectrometer.

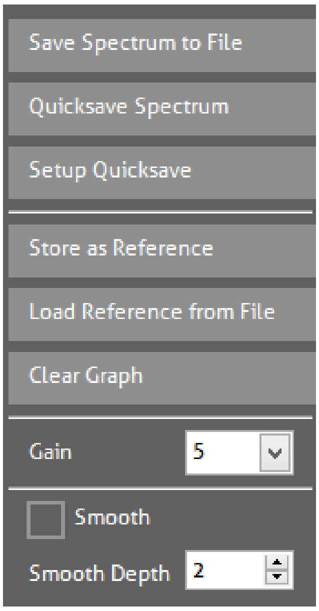


Figure 4.9.: Menu of the activated SPECTRUM section

- **Save a spectrum measurement**: Additionally to a common save function to take a sample spectrum a ”Quicksave Spectrum” option offers a tool for fast measurement by simply pressing the respective button. This function requires information on file name and location that has to be defined under ”Setup Quicksave” before. An increasing counter is then added to the file name each time the quick save option is used.
- **Store and display a reference spectrum**: By pressing the ”Store as Reference” button a spectrum is saved for further comparison. This reference spectrum is displayed as a green graph together with the currently measured spectrum. Such a reference graph can also be loaded by pressing the ”Load Reference from File” button. The ”Clear Graph” function removes the green reference spectrum from display.
- **Gain**: The spectrometer gain can be adapted in four steps (gain = 1, 2, 5, 10) to increase or decrease the spectrum. The software tuning routine levels the spectrometer gain automatically.
- **Smooth**: A noisy spectrum can be smoothed by setting a check mark and adapting the ”Smooth Depth” value. This value represents the numbers of adjacent spectral data points that are averaged.

4.3.5. The TUNING Menu

The TUNING menu shows the actuator controls and start/stop buttons for the offered functional routines. This menu can be set for permanent visibility by setting a check mark at "Show Actuators" in the VIEW menu. These controls give full access to the actuators inside the optics unit to manually find and optimize the OPO Signal. The button of a functional routine (e.g. "Search" or "Maximize" signal) that is inactive has a grey color while a black button highlights a currently running routine. By pressing a grey button the respective routine is started and the button switches to black color. Each routine can be stopped prematurely by pressing the respective black button. If one routine for a certain actuator is active no second routine of the same actuator can be started at the same time.

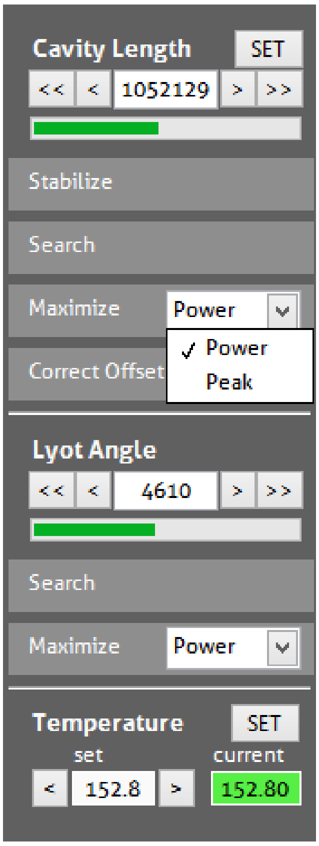


Figure 4.10.: TUNING menu section to manually optimize the OPO Signal via software controls and automatic routines for the individual actuators. This menu is visible by default in the "Manual" tuning mode.

Figure 4.10 shows the TUNING menu that is arranged in three sections:

- Top: Controls and automatic routines using the cavity length actuator to synchronize the OPO cavity with the repetition rate of the pump laser for a chosen signal wavelength.

- Center: Controls and automatic routines using the actuator of the Lyot-filter for fine adjustment of the signal wavelength.
- Bottom: Controls for the actuator to set the temperature of the OPO-crystal for proper phase-matching.

Cavity Length

This actuator controls the position of the M2 mirror and therefore the cavity length (see Figure 3.2).

- **Set**: Pressing this button sets the cavity length to the calibrated position for the input wavelength of the tuning section (see number 4 in Figure 4.3).
- $<< / < // > / >>$: The arrow buttons change the cavity length in two different step sizes.
- **Position control** of the cavity length actuator: The position number control between the arrow buttons acts as numeric indicator of the current position and as a control to enter an absolute M2 position in digits. The resolution is $\approx$ 70000 dig/mm and the range goes from 500.000 to 2.000.000. (The exact limits are device specific.) The green bar below is a second bargraph indicator for the position.
- **Stabilize**: In case of an optimized signal its power can be stabilized with the cavity length actuator to compensate thermal drifts by pressing the "Stabilize" button. To deactivate this hold function the button has to be pressed again.
  The tolerance of this stabilization (i.e. necessary parameter deviation to start active control) can be monitored and changed in the SETUP menu (see Section 4.3.3).
- **Search**: In case all parameters of the OPO are set properly the "Search" routine scans the cavity length and stops if signal power is detected. Pressing this button starts the search signal routine and the button color switches to black. The button is set back to grey if the routine stops successfully or without success after a full scan. For a successful signal search several preconditions are required:
  1. The OPO crystal has to be heated at the right temperature for phase-matching at the desired signal wavelength.
  2. The M2 mechanical slider is fixed at the proper number engraved in the rail. This number can be taken from the "Show M2 Position" , see Section 4.3.7.
  3. The OPO cavity and detection should be pre-aligned according to the alignment procedure described in the manual, see Chapter 5. Even if the OPO is not yet running, prealignment of the diagnostic beam path is possible with residual green pump radiation.
- **Maximize**: In case the OPO is already generating a signal this routine can be used to find the correct cavity length for either maximum signal power (if the respective

drop down control is set to "Power") or maximum spectrometer peak (if the drop down control shows "Peak"). Both routines ignore signal peaks that might rise in other Lyot orders than the one in which it started. The "Peak" maximization routine suppresses signal side peaks more efficiently especially at wavelengths longer than 900 nm.

- **Correct Offset**: The positioning of the M2 mirror is based on a dispersion polynomial. After initial setup of the OPO or realignment of the pump beam or cavity an offset correction is necessary for fast and robust automatic tuning. It is recommended to do this correction in the middle of the wavelength tuning range, i.e. around 800 nm.

Lyot Angle

This actuator controls the angle of the motorized intra-cavity Lyot-filter for fine tuning the signal wavelength (see LF in Figure 3.2).

- << / < // > / >> : The arrow buttons change the angle in two different step sizes.
- **Position control** of the Lyot-angle actuator: The position number control between the arrow buttons acts as numeric indicator of the current stepper motor position and as a control to enter the desired Lyot angle position in digits (between 0 and 10.000 - the exact limits can be device specific. The green bar below is a second bargraph indicator for the position.
- **Search**: Normally, in case all parameters of the OPO are set properly and also the cavity length is set to their calculated position the OPO generates a signal independent on the exact Lyot-angle setting. However, especially for systems pumped at 532 nm there are Lyot-angle positions that completely suppress signal generation in the short wavelength range. In this range the search signal routine with the Lyot-angle actuator can be used to start the OPO. (For a first initial start of the OPO it is recommended to choose a phase-matching temperature of the OPO crystal for a signal wavelength >700 nm to avoid this regime.)
- **Maximize**: Due to the characteristics of the Lyot-filter the successive interference orders can show different transmission rates. In case the OPO is already generating a signal this routine can be used to find the Lyot order with the highest signal transmission if the respective drop down control is set to "Power". In case the drop down control is set to "Peak" the routine suppresses signal side peaks more efficiently.

Temperature

This section handles the temperature control for phase-matching the OPO crystal (see Figure 4.10).

- **Set** button: Pressing this button inserts the calibrated set temperature value for phase-matching the Signal [nm] set wavelength of the GUI's tuning section (see number 4 in Figure 4.3). The OPO crystal is stabilized at the new temperature.
- **Set** temperature value: This is a control to enter a desired numeric value for the destination temperature in °C.
- $< // >$: The arrow buttons change the set temperature value in 0.1°C steps.
- **Current** temperature: This indicator shows the actual measured temperature of the OPO crystal in °C. The measured temperature value is highlighted with a green background as soon as it is stabilized at the set temperature value.

4.3.6. The SWEEP Menu

The SWEEP menu offers the configuration and control of a special tuning procedure (see figure 4.11). This procedure allows a fast successive scan of signal wavelengths in steps defined by ”Step [nm]” between a start (”Start [nm]”) and a stop (”Stop [nm]”) value. Alternatively, a number of sample steps (”Samples”) can be entered instead of a step length. At each intermediate set wavelength (indicated in ”WL set [nm]”) the routine either waits a certain hold period defined by ”Hold [s]” or waits for a software trigger (button ”Trigger” or TCP/IP command SWEEP_TRIGGER) if the hold time is set to ”-1”. At around 800 nm signal wavelength the routine works over several 10 nm with a maximum step length of 2 nm.

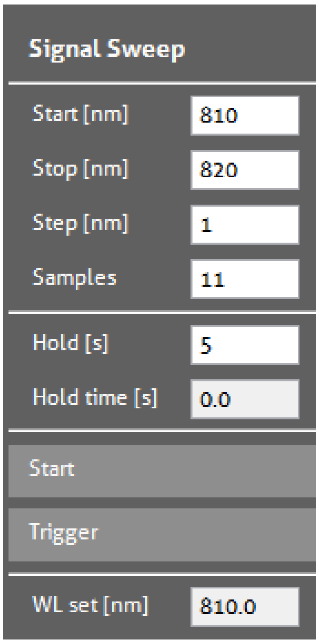


Figure 4.11.: Menu of the activated SWEEP section

In the following the controls to configure a signal wavelength sweep are listed:

- **Start [nm]** input: Set a start signal wavelength in nm.
- **Stop [nm]** input: Set a stop signal wavelength in nm.
- **Step [nm]** input: Set the signal step length in nm. The number of samples for the signal wavelength is automatically calculated and inserted in the ”Samples” control.
- **Samples** input: Instead of a step length in nm a number of sample signal wavelengths can be set. The respective wavelength step is calculated assuming equidistant wavelength steps and inserted in the ”Step [nm]” control.

- **Hold [s]** input: Set a hold time in seconds to wait at each intermediate signal wavelength before the sweep tuning continues to the next. A value of -1 sets the hold time to infinity and the sweep routine waits for further interaction.
- **Hold time [s]** display: Shows a real time counter from 0 to the Hold [s] value.
- **Start** button: Start/Stop button for the configured sweep tuning sequence.
- **Trigger** button: Press this button to continue the sweep tuning to the next signal wavelength before the hold time is over.
- **WL set [nm]** display: Shows the next signal wavelength set for the sweep.

After configuration of the sweep parameters and starting the routine the software tunes the OPO with the standard procedure to the start wavelength. This might take up to 4 minutes depending on the necessary temperature step. After successful tuning the function holds the wavelength for a time period defined by the hold time. Then, cavity length and temperature are set with respect to the internal calibration curves and the Lyot-angle is adapted to tune to the next set wavelength ("WL set [nm] = Start [nm]+Step [nm]"). This is accomplished within 5 seconds followed again by the hold time. Then the system moves further to the next set wavelength until the stop wavelength is reached.

4.3.7. The HELP Menu

The HELP menu provides information about the device, settings and links to web pages (**APE**Website, **APE**Calculator).

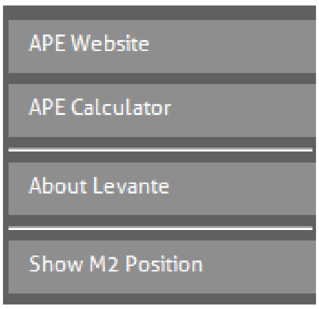


Figure 4.12.: Menu of the activated HELP section

- **About Levante**: This button opens a separate information window that shows all relevant software and firmware version and serial numbers of the device and the integrated modules. In addition a text file with the same information is saved on the computer at "C:\Users\Public \Documents\APE\LevEm_OPO\module_ versions.txt".
- **Show M2 Position**: This button opens a message window with the important information on the correct position of the M2 mirror slide on the ruler rail (see Figure

4.13). This position is calculated from the cavity configuration, optics and repetition rate of the pump laser. All these necessary parameters are taken from the configuration file, and only the repetition rate used for the calculation can be adapted in the SETUP menu (see section 4.3.3). Though the calculated number has a higher accuracy than the resolution of the ruler it is sufficient to position the slide at the approximate position ($\approx \pm 2\,\mathrm{mm}$). Because the manual positioning of the slide is not precise enough for automatic tuning an offset correction of the wavelength calibration of the cavity length actuator position is necessary (see Section 4.3.5).

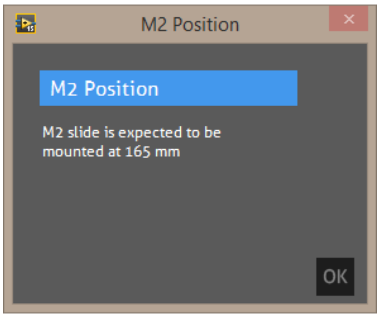


Figure 4.13.: Message window for information on the correct M2 slide position on the ruler rail. The reference line for the ruler is the arrow at the back side of the slide, see Figure 5.4.

5. Installation of the System and Optical Alignment

5.1. Description of the Optical Unit

A detailed top-view scheme of the **Levante Emerald** OPO cavity with installed signal / idler separation is depicted in figure 5.1. The path of the pump beam is marked as a green line. In front of the beam splitter BS1 the pump beam is separated from the co-propagating signal / idler beam and is guided out of the cavity housing on a beam dump. The resonant signal beam inside the OPO cavity is represented by a red line. The red marked signal beams reflecting off the beam splitter BS1 are for diagnostic means to measure the signal power with PD2 and the signal spectrum with the waveScan internal spectrometer. For the further description of the device installation and alignment steps the positions of the various alignment apertures are marked in blue colour. For a reproducible cavity alignment defined blind holes in the OPO ground plate (blue circles in figure 5.1) mark the position of the pluggable alignment aperture. This aperture and a second alignment aperture that is freely placeable is delivered as additional tools (see figure 5.2).

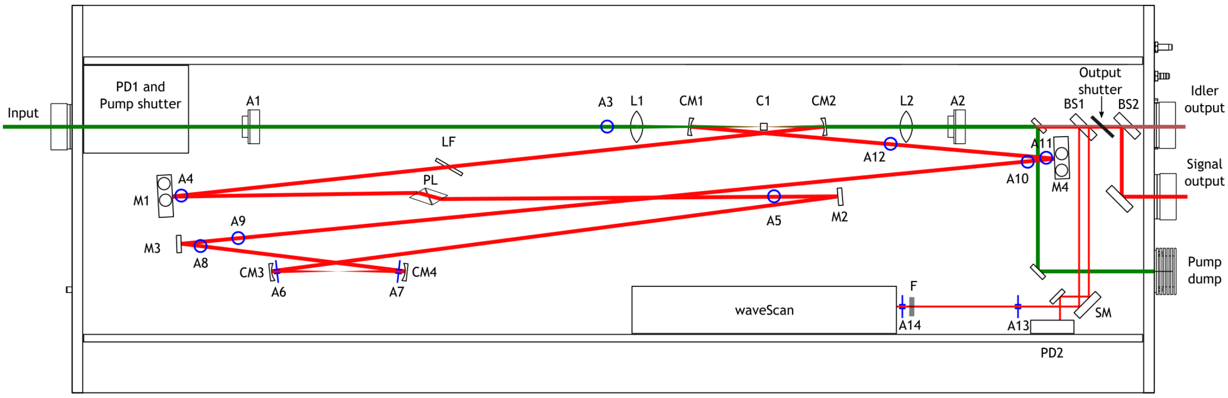
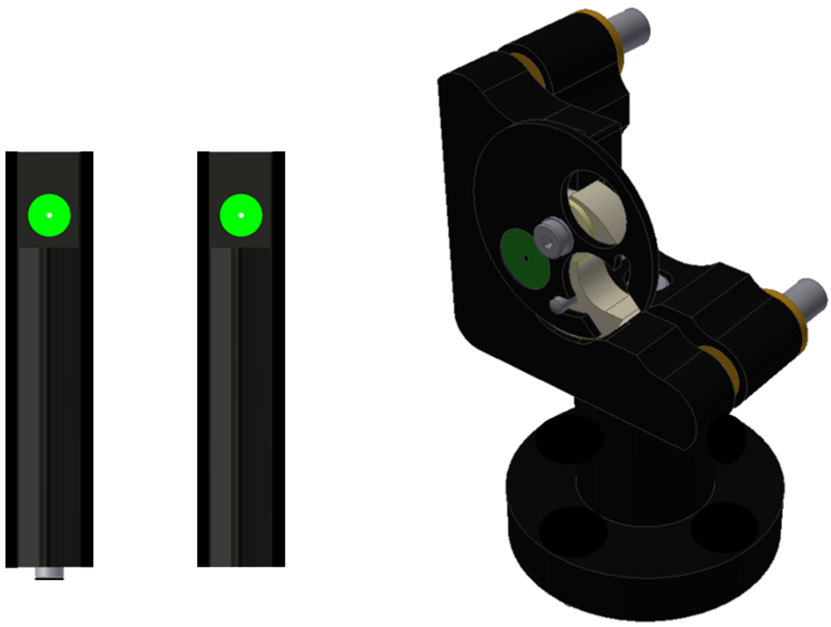


Figure 5.1.: Top view of the **Levante Emerald** OPO optical unit

The following components are marked in Figure 5.1:

CM1, CM2, CM3, CM4	Concave cavity mirrors
CM2	Output coupler for the signal and idler radiation
M1, M2, M3, M4	Plane cavity mirrors
M2	mounted on a motorized stage
A1, A2	Alignment iris apertures for the pump beam
A3	Position for pluggable aperture for pump beam
A4, A5, A8 ... A11	Positions for pluggable aperture for cavity alignment, see Fig. 5.2 a)
A12	Position for freely positionable aperture, see Fig. 5.2 b)
A6, A7	flip apertures at CM3 and CM4 mounts for cavity alignment, see Fig. 5.2 c)
A13, A14	flip apertures for diagnostic beam
C1	heated LBO-crystal
L1	Pump focussing lens
L2	Output collimation lens
LF	Lyot birefringent filter
PL	Polarizer
BS1	Beam splitter for signal beam diagnostic
BS2	Beam splitter for signal / idler separation
SM	Steering mirror
F	pivoting neutral density reflective filter
PD1	Pump power photo detector
PD2	Signal power photo detector
waveScan	Internal spinning-grating spectrometer



a) b) c)

Figure 5.2.: a) Pluggable aperture, b) freely positionable aperture used for alignment, c) flip apertures in front of CM3 and CM4.

5.2. First Installation / Setup of the Levante Emerald

5.2.1. Pump Beam Alignment

Before set-up of the OPO on the optical table it is recommended to prepare the pump laser beam:

- Set the pump laser into an alignment mode or manually decrease the intensity to a safe level (about 100 mW or less). Please take care of your own safety and the ones surrounding you. Common laser safety practices do apply. Please refer to Chapter 2 for further information.
- Make sure, that the pump light is polarized vertically to the optical table.
- Place two beam steering mirrors behind the pump laser to prepare a beam distance of about 400 mm between the laser and the OPO device. Please use the delivered pump optics set.
- Align the pump beam parallel to the plane of the optical table at a beam height of $\approx$ 125 mm.

Synchronously pumped OPO

Once the pump beam is set up, the OPO can be placed in the beam path. The beam distance this device is configured for is noted on the device configuration sheet as well as on the test report. For the standard configuration the beam distance may vary from 30 ... 55 centimeters.

Any other setup than the one described on the device configuration sheet may damage your device.

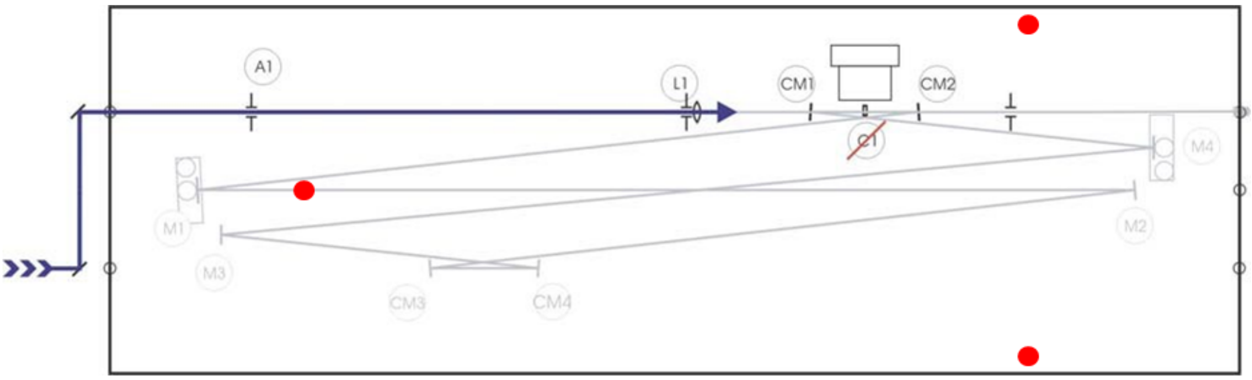


Figure 5.3.: Initial pump beam alignment into the OPO. The positions of the leveling screws and feet for clamping are marked as red circles.

- Put the OPO on the optical table behind the laser with two beam steering mirrors between both instruments, so that the pump beam enters the entrance window perpendicular and centered (see figure 5.3).
- Open and remove the two covers of the OPO optical unit.
- Take the crystal out of the heater module if its already mounted (see figure 5.5). Caution, don't touch the metal parts of the crystal holder. When OPO power is switched on and the crystal holder is connected with the electronics, the crystal and holder will be heated to about 100 °C as standby temperature! Do not clean a heated crystal!
- Connect power supply, grounding cable, interlock cable or jumper and the controller PC via USB to the OPO optical unit as described in chapter 3.3 (see figure 3.5).
- Switch on OPO power and the controller PC. Start the OPO software "Levante Emerald NSP.exe" as described in chapter 4.1.

For safety reasons the cover triggers two switches, which are connected to the interlock circuit, i.e. the pump shutter will close or will not open respectively, when the covers are removed. These switches have three possible states (see Figure 2.3). For alignment purposes pull out the knobs to set the interlock switches into alignment mode. This will allow you to open the pump shutter although the covers are taken away and proceed with the alignment.

- Use the software to open the pump shutter. (Note: there is a safety time of 120 seconds after power on of the OPO when opening the pump shutter is not possible.)

- Level the OPO horizontally exactly to the height of the pump laser. Use the leveling screws (see Figure 5.3) to change the height of the OPO. Close aperture **A1** and place the plug aperture at position **A3**.
- Position the OPO housing, until apertures **A1** and **A3** are hit. Use the foot clamps to fix the OPO in position.
- Center the input beam with the two pump beam steering mirrors on **A1** and **A3** (Fig. 5.3). Remove plug aperture from **A3** and check if the pump beam position is centered also at position **A2**.

5.2.2. Cavity Alignment

- See for the repetition rate of the pump laser in the laser test protocol or measure it with a frequency counter using a photodiode output signal. Compare it to the pump frequency displayed in the SETUP menu (or in the info window) of the software. In case there is a difference of more than 0.2 MHz, insert the measured value in the SETUP menu.
- Open the HELP menu and press the "Show M2 Position" button. If the displayed position value (compare figure 4.13) differs by more than $\approx 5\,\mathrm{mm}$ from the current position, fix the M2-slider at the new expected position (see figure 5.4).

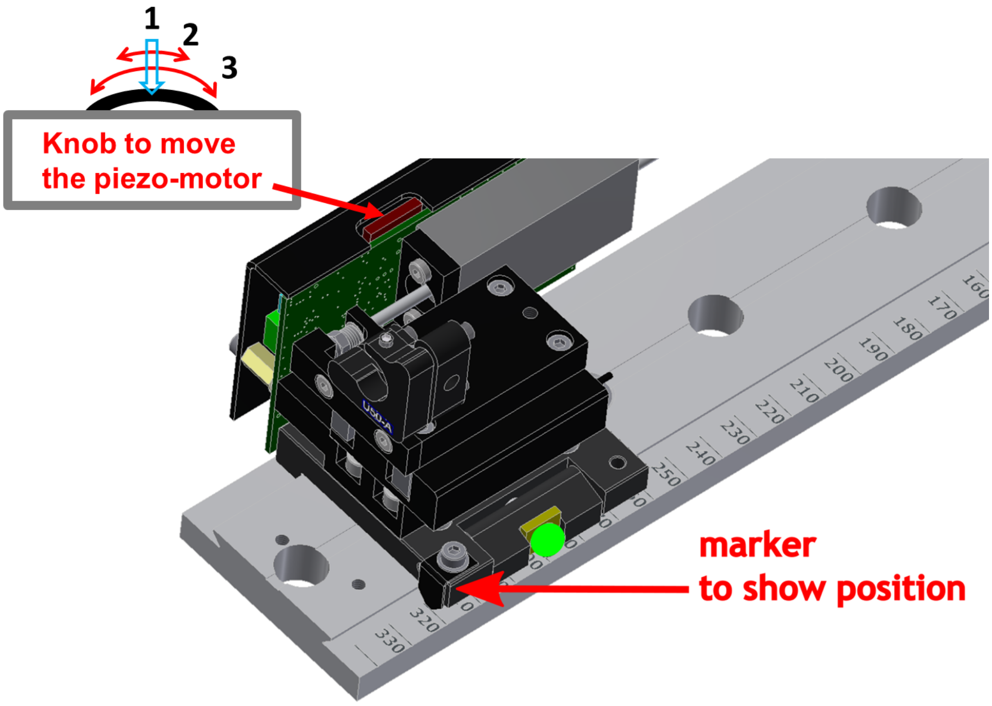


Figure 5.4.: Cavity length actuator module (to shift the M2 mirror position) mounted on a slider on the ruler rail. Green marked: fixing screw of the slider; The reference line to define the slider position is marked. Loose fixing screw to shift the slider to its new position for a different pump laser repetition rate.
For fine cavity length adjustment use the marked knob to move the piezo-motor. 1: Press the knob to switch between to speed levels. 2: Turn the knob to a small amplitude to move in slow mode of the respective speed level. 3: Turn the knob to maximum amplitude to move in fast mode of the respective speed level.

The next step describes the crystal alignment, so that it is hit centrally and in line with the pump beam.

Caution, make sure to work with an average pump power of 100 mW or less!

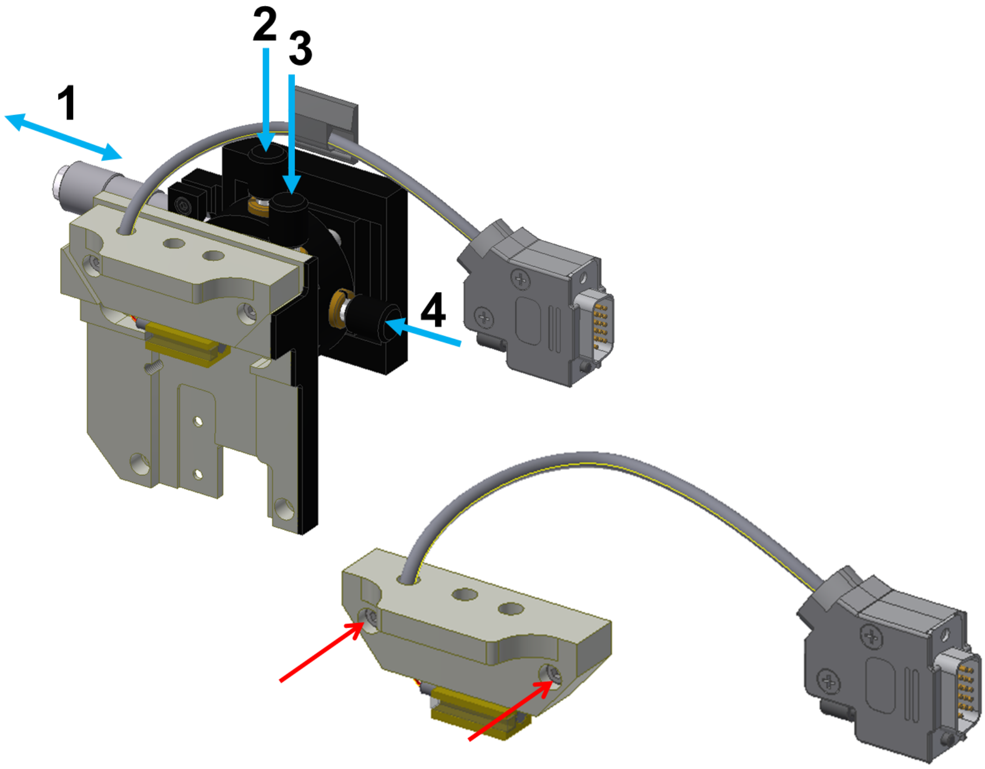


Figure 5.5.: Four axis crystal heater mount (left): (1) horizontal translation micrometer screw, (2) crystal height alignment screw, (3) crystal vertical tilt adjustment screw, (4) crystal horizontal tilt adjustment screw, and crystal holder (right): red arrows show positions of crystal holder fixing screws.

Caution: **Don't touch the metal parts of the crystal holder. When OPO power is switched on and the crystal holder is connected with the electronics, the crystal and holder will be heated to about 100 °C (standby temperature) or more! Do not clean a heated crystal!**

Take care: **Always leave the optical unit with power on if the OPO-crystal is installed. Even if the software is switched off the heater is hold at a standby temperature of 100 °C to protect the strongly hygroscopic LBO material from humidity. Otherwise, store the crystal in a drying chamber for protection.**

- Exit the software if its running and power off the OPO.
- Clean the OPO crystal (with methanol) if crystal and holder are at room temperature.

- Close aperture **A1** and make sure that the pump beam is blocked (pump shutter is closed if software is not running).
- Place the crystal holder in the 4-axis mount and tighten the crystal holder with the 2 mounting screws (Fig. 5.5). Plug the connector to the electronic aside.
- Set the micrometer screw (1) to the position given in the test report.
- Align the vertical and horizontal tilt angle (3,4) parallel to the base plate and approximately parallel to the side wall.
- Power on the OPO and start the software. The crystal will be heated to the standby temperature of 100 °C.
- Open the pump shutter after waiting an initialization time of 120 s (pump power still at 100 mW or less, aperture **A1** still closed).
- The crystal needs to be aligned perfectly perpendicular to the pump beam. Correct the tilt angle of the crystal with (3) and (4) by monitoring the pump beam back reflection as follows:

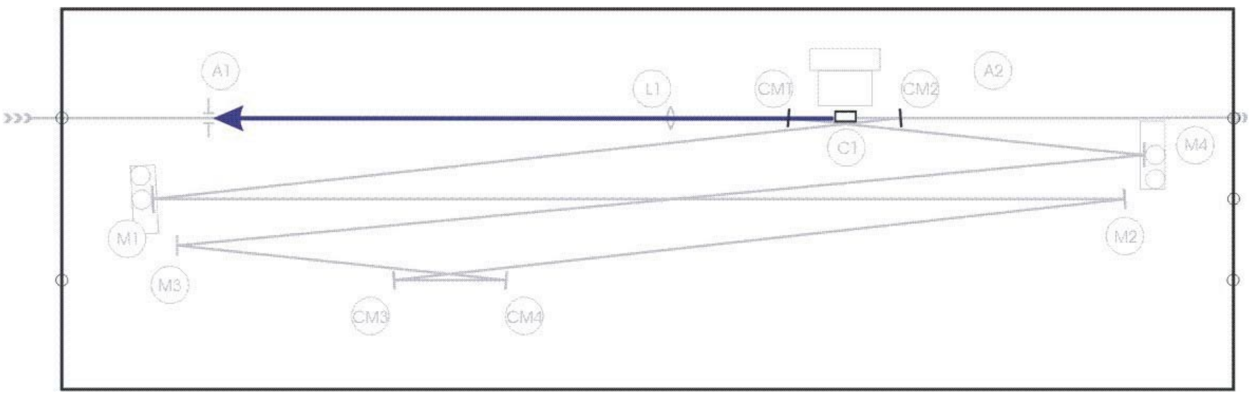


Figure 5.6.: Monitor and align pump back reflections from the crystal.

- First set the crystal back reflection to **A1** (Fig. 5.6, make sure aperture **A1** is closed and the plug aperture at **A3** is removed).
- For fine alignment place an alignment aperture at position **A11** in front of M4. The back reflection from the front and the back face of the crystal should be visible as small and bigger spot (Fig. 5.7 a) and overlap (Fig 5.7 b). Place the alignment aperture at position **A9** in front of M3 and check the overlap again.

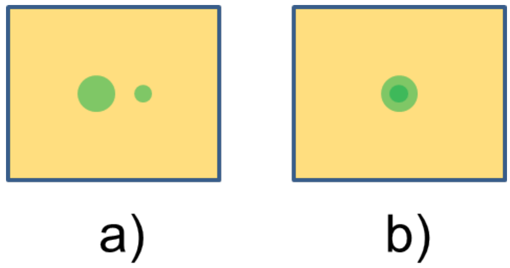


Figure 5.7.: Pump beam back reflections from the crystal.

- Insert 770 nm as signal set wavelength in the software and press the temperature ”Set” button.
- Block the beam between CM2 and M1 using the beam block tool and open aperture **A1**.

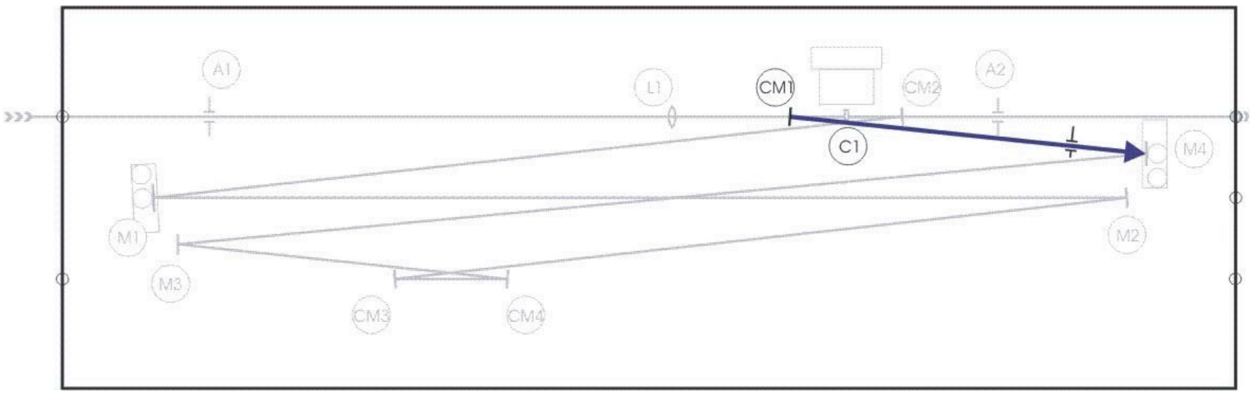


Figure 5.8.: Align CM1 to center green pump spot on M4. Use plug aperture position **A11**.

- Place the plug aperture at position **A11**. Use the pump beam backward reflection from the crystal and adjust CM1 to center spot on M4 (Fig. 5.8).

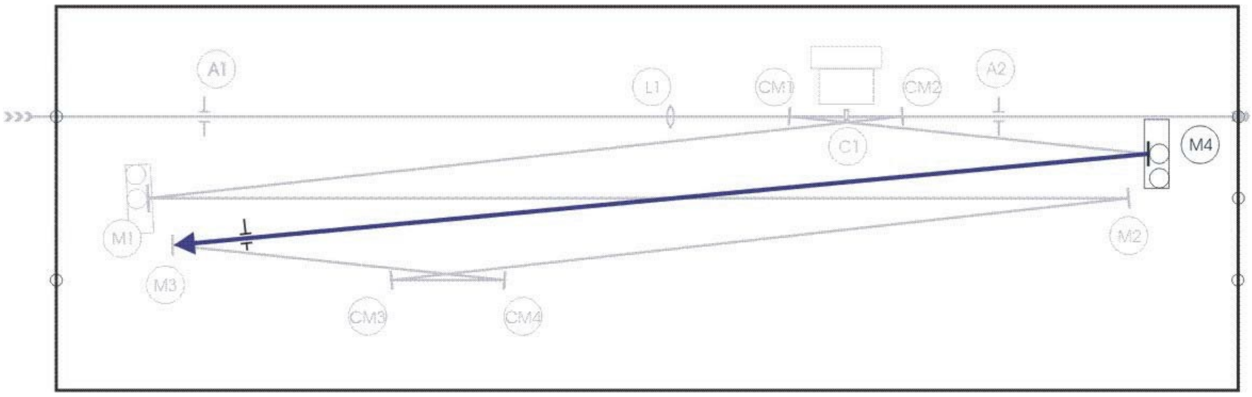


Figure 5.9.: Align M4 to center green pump spot on M3. Use plug aperture position **A9**.

- Place the plug aperture at position **A9**. Adjust M4 to center the spot on M3 (Fig. 5.9).

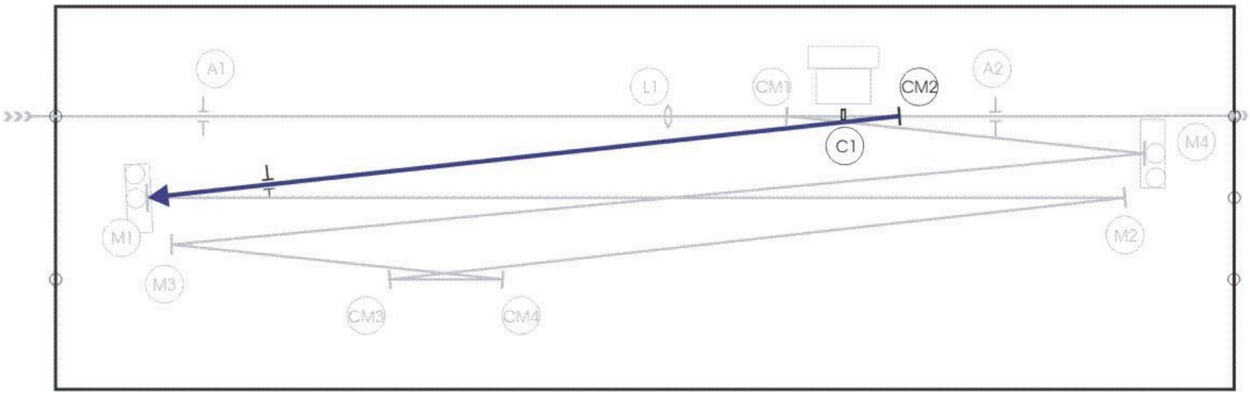


Figure 5.10.: Align CM2 to center green pump spot on M1. Use plug aperture position **A4**.

- Unblock the beam between CM2 and M1.
- Block the beam between CM1 and M4 using the beam block tool.
- Place the plug aperture at position **A4**.
- Use the green pump spot in forward directions and adjust CM2 through the Lyot filter to center the green spot on M1 (Fig. 5.10)

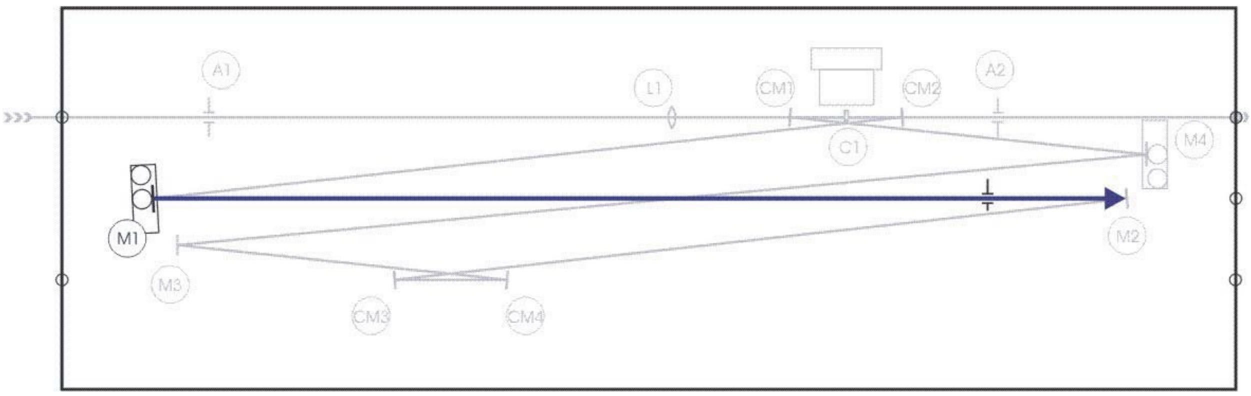


Figure 5.11.: Align M1 to center green pump spot on M2. Use plug aperture position **A5**.

- Place the plug aperture at position **A5**. Adjust M1 to center the spot on M2 (Fig. 5.11).

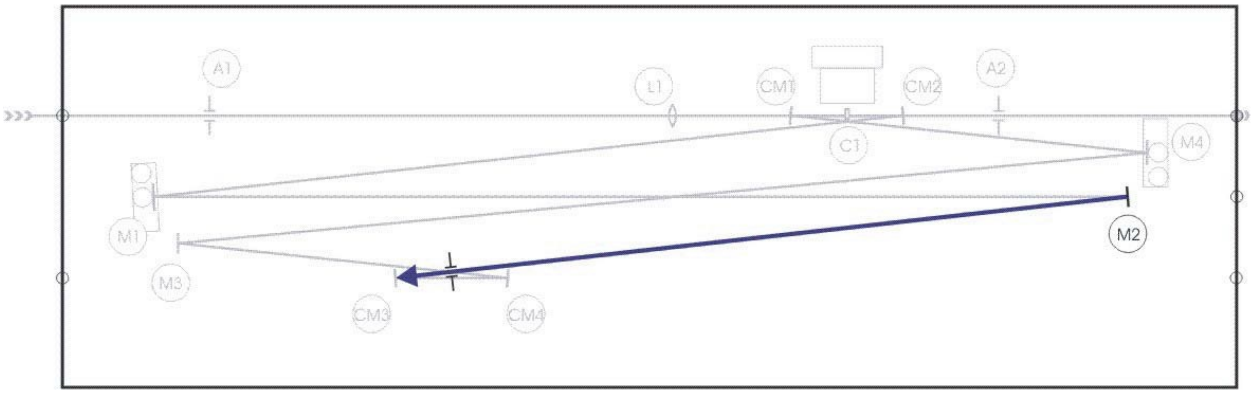


Figure 5.12.: Align M2 to center green pump spot on CM3. Use flip aperture **A6**.

- Flip in aperture **A6** in front of CM3. Adjust M2 to center the spot on CM3 (Fig. 5.12).

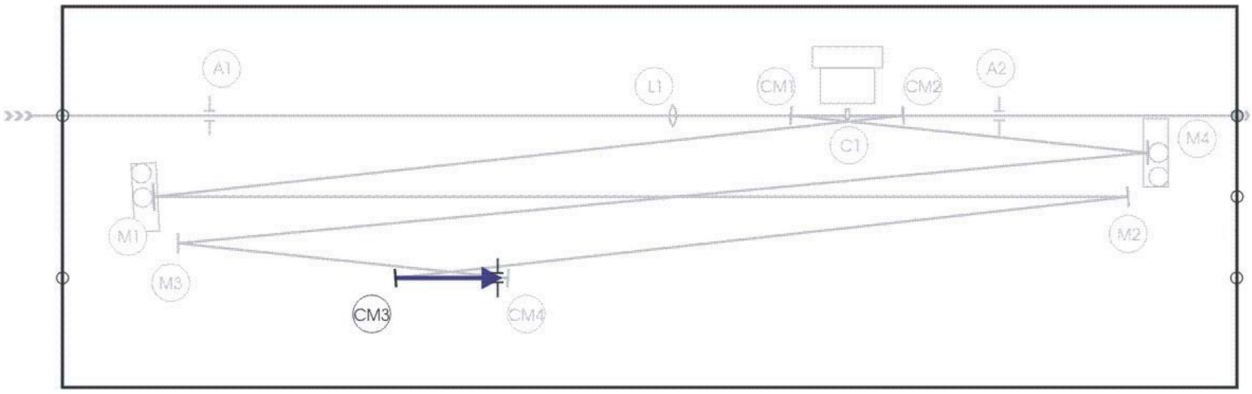


Figure 5.13.: Align CM3 to center green pump spot on CM4. Use flip aperture position **A7**.

- Flip out aperture **A6**.

- Flip in aperture **A7** in front of CM4. Adjust CM3 to center the spot on CM4 (Fig. 5.13).

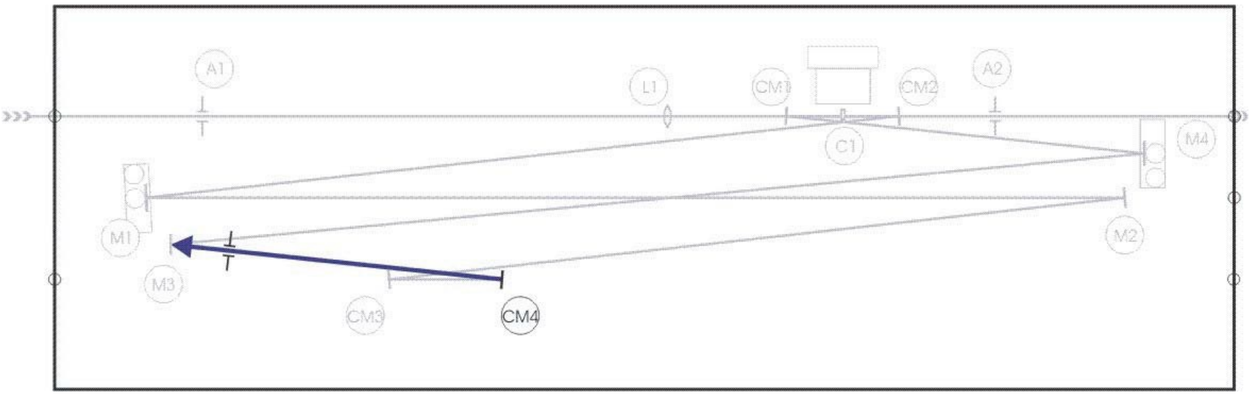


Figure 5.14.: Align CM4 to center green pump spot on M3. Use plug aperture position **A8**.

- Flip out aperture **A7**.

- Place the plug aperture at position **A8**. Adjust CM4 to center the spot on M3 (Fig. 5.14).

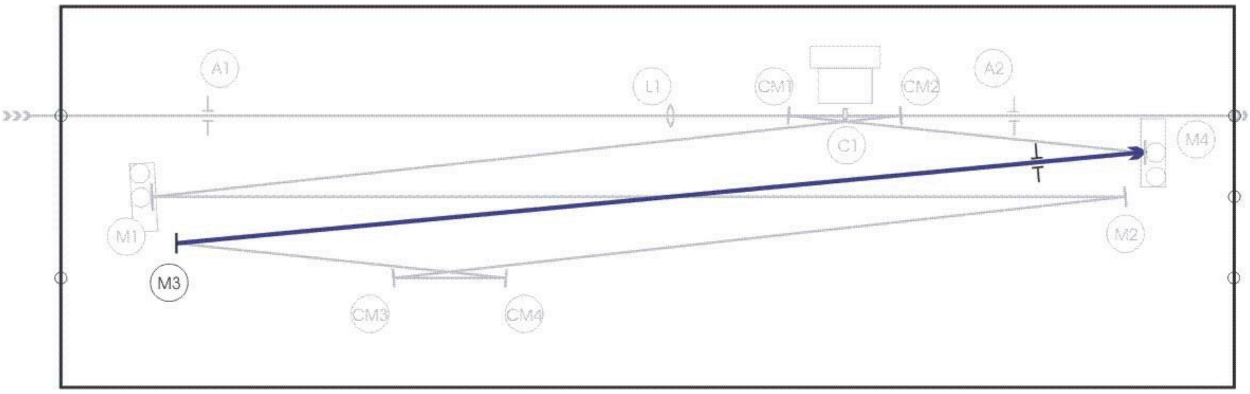


Figure 5.15.: Align M3 to center green pump spot on M4. Use plug aperture position **A10**.

- Place the plug aperture at position **A10**. Adjust M3 to center the spot on M4 (Fig. 5.15).

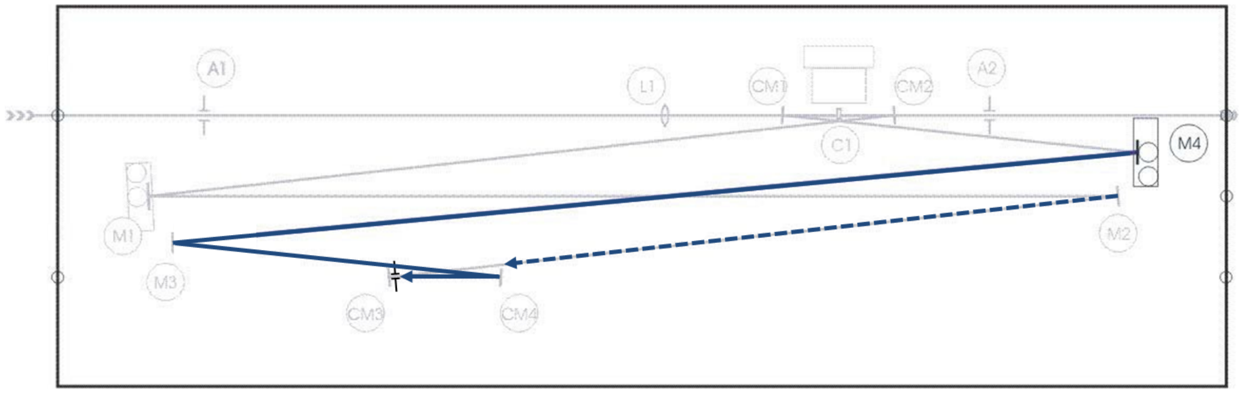


Figure 5.16.: Check forward transmitted pump beam (dotted line) alignment on **A6** and correct backward reflected pump beam (solid line) with M4 to overlap both spots on **A6**.

- Flip in aperture **A6** in front of CM3 and check that the beam from M2 is already centered.
- Unblock the beam from CM1 to M4 and block the beam from CM2 to M1 using the beam block tool.
- Adjust M4 to bring the green spot from M4 via M3 and CM4 onto the hole of the aperture **A6** to overlap forward and backward reflection (Fig. 5.16).

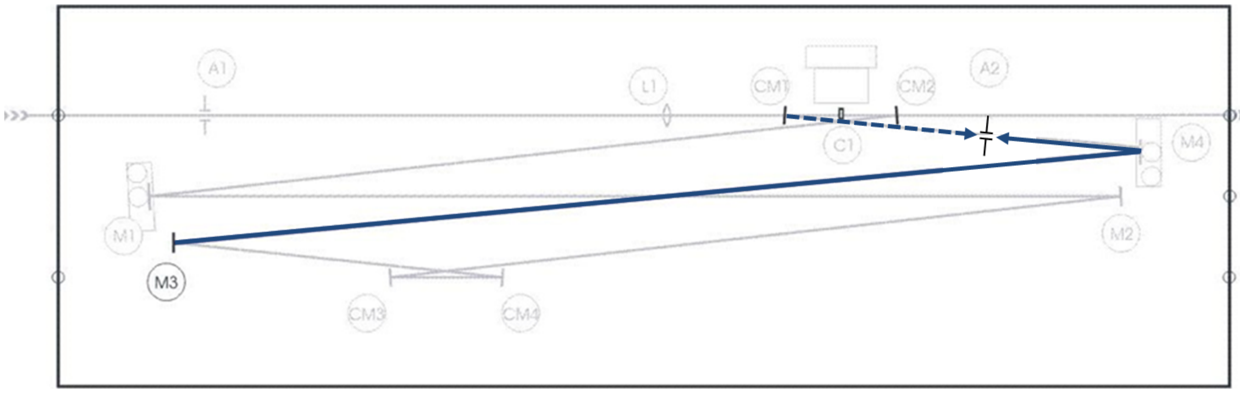


Figure 5.17.: Check the backward reflected pump beam (dotted line) alignment on aperture at **A12** position and correct the forward transmitted pump beam (solid line) with M3 to overlap both spots on the aperture.

- Use the freely positionable aperture (Fig. 5.2 b) and place it near position **A12** between M4 and CM1 so that the backward reflection from CM1 passes through.
- Unblock the beam from CM2 to M1.
- Overlap the green spots from the forward and backward reflection adjusting M3 only (Fig. 5.17).

- Repeat the steps of the last two pictures (Fig. 5.16 and Fig. 5.15) until a good overlap at both positions of the aperture is achieved.

- Close aperture A1 and place the plug aperture at position **A3** in front of L1 again. Raise pump laser power to operating power. Check whether pump beam alignment has changed and correct if necessary. Block pump laser and open both apertures again.

- Change cavity length slowly using the motor button (see Fig. 5.4) until OPO starts generating. This can be seen either by a reduction of the green pump intensity behind CM2 or with an IR card behind the OPO exit (make sure the OPO output shutter is open). In case the phase-matching temperature was set for e.g. 770 nm the red signal beam should be visible also on a white card.

5.2.3. OPO Optimization

After the **Levante Emerald** is generating a signal the cavity needs fine adjustment to maximize the signal power and to optimize the output beam mode structure:

- Place a power meter in the signal beam behind the OPO exit port.

- Optimize the OPO output power by fine tuning of the cavity length with the software buttons.

- Optimize the OPO output power by tuning of the Lyot-filter angle with the software buttons.

- Align the OPO cavity with the mirrors M1 and M4 to an optimal mode structure and maximum power.

- Maximize OPO output power with crystal and lens positions (C1 and L1 horizontal translation with the micrometer screws) and mirror alignment (M1, M4) under continuous control of the mode structure.

5.2.4. Diagnostic Beam Alignment

For automatic tuning precise alignment of the diagnostic beams from the beam splitter BS1 via the steering mirror SM to the photo diode PD2 (signal power detection) and into the internal spectrometer (waveScan for signal spectrum detection) is necessary:

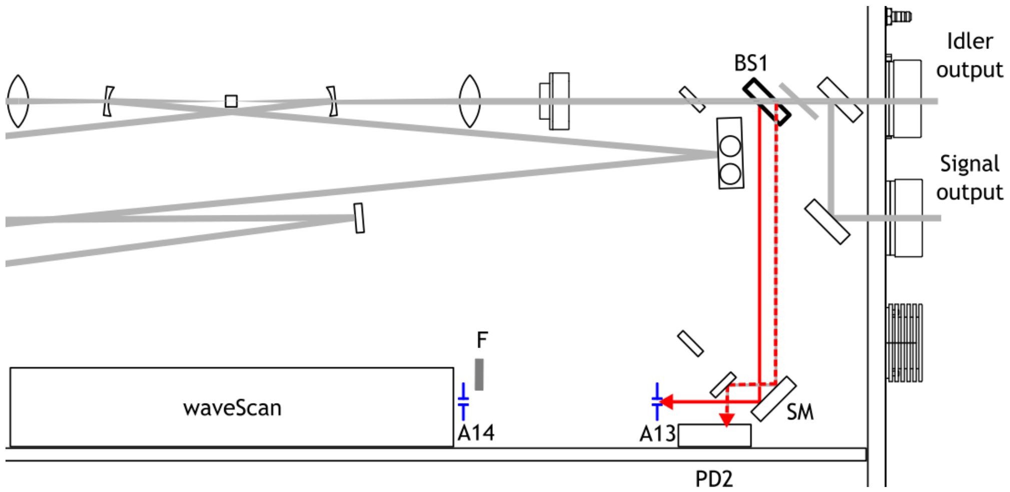


Figure 5.18.: Diagnostic beam alignment - step 1: Align BS1 to center front reflection on **A13**.

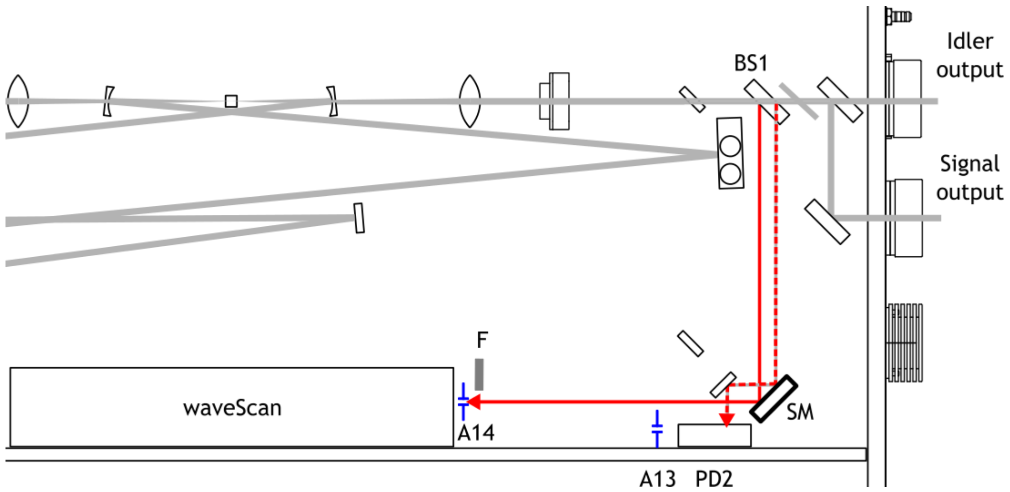


Figure 5.19.: Diagnostic beam alignment - step 2: Align SM to center front reflection beam on **A14**.

- Turn alignment apertures **A13** and **A14** in the beam path as shown in Fig. 5.18.
- Turn the reflective neutral density filter **F** away from the spectrometer entrance (see 5.18).
- Align the beam splitter **BS1** to center its front reflection beam on aperture **A13**. Use an IR-viewer if necessary.
- Turn aperture **A13** out of the beam and align with the steering mirror **SM** to center the beam on **A14** (see 5.19).
- Repeat these steps until the front reflection beam from **BS1** is centered on **A13** and **A14**.

- Remove both apertures **A13** and **A14** and monitor the spectrometer display on the software GUI whether a signal peak already appears (Fig. 5.20).
- Increase spectrometer gain and zoom the intensity axis if necessary.
- First, slowly change the vertical alignment of the steering mirror **SM** to find or maximize the signal spectrometer peak. Further maximize the peak with the horizontal **SM** alignment. Adapt intensity zoom factor and spectrometer gain if necessary to avoid signal peak saturation.
- In case of signal peak saturation of the spectrometer at the minimum gain factor of 1, turn in the reflective neutral density filter **F**.
- Turn in alignment aperture **A13** and check if the beam is already centered. Correct with **BS1** alignment if necessary - then turn out **A13** and maximize the spectrometer signal with **SM** again.
- Repeat the last step until both conditions (beam centered on **A13** and maximum spectrometer signal with apertures removed) are fulfilled. Under this condition also the second diagnostic beam (from the back side of **BS1**) should be centered on the signal power detector **PD2**. A certain signal power value should already be displayed in the info window of the software.

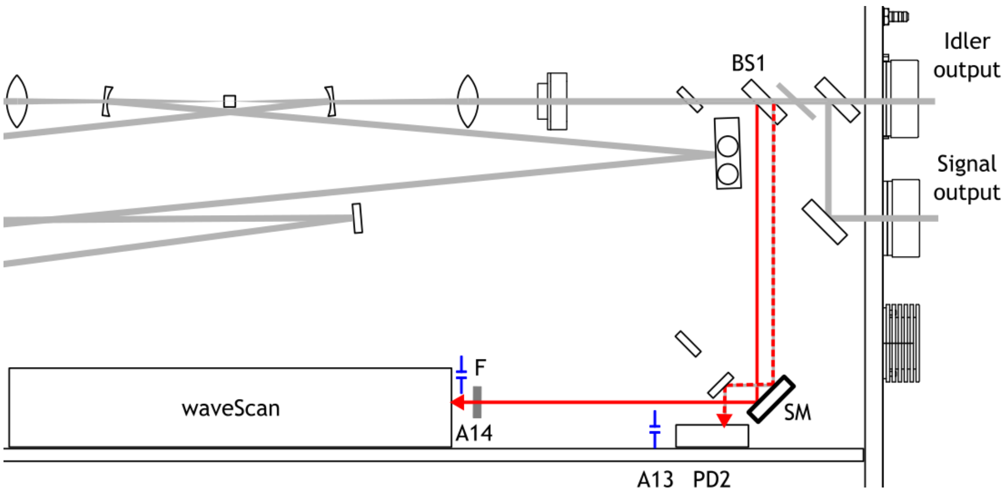


Figure 5.20.: Diagnostic beam alignment - step 3: Align SM to maximize the signal spectrometer peak.

Caution: **After significant cavity alignment the diagnostic beam alignment should be checked and corrected as described above to ensure proper automatic tuning with the software!**
For proper operation, make sure that both apertures A13 and A14 are turned out of the diagnostic beam to the spectrometer. Use the attenuator F only if the signal spectrum saturates in the maximum of the wavelength tuning curve for a spectrometer gain value of 1.

5.3. Quick Alignment / Daily Optimization Routine

- Reduce the pump power to alignment level of about 100 mW.
- Start the **Levante Emerald** OPO software.
- Insert a set signal value of 800 nm and press the ”SET” buttons for ”Cavity Length” and ”Temperature” in the ”TUNING” menu.
- Open the covers of the **Levante Emerald** optical unit.
- Close aperture **A1** and place the plug aperture at position **A3** and pull out both interlock switches.
- Use the software to open the pump shutter and check if the pump beam is centered on **A1** and **A3** (see Fig. 5.3).
- Close the pump shutter, open aperture **A1** and remove aperture from position **A3**. Open the pump shutter again.
- Turn in aperture **A6** in front of CM3 and check the overlap of the forward and backward reflected pump beam (Fig. 5.16). Correct with M4 adjustment if necessary.
- Turn out aperture **A6** and place the freely positionable aperture between CM1 and M4 that the backward reflected pump beam from CM1 passes through (Fig. 5.17). Overlap the green spots from the forward and backward reflection adjusting M3 only.
- Repeat the last two steps in an iterative procedure a few times until a good overlap at both positions of the aperture is achieved.
- Increase pump power to normal operation level and check carefully with the iris aperture **A1** if the pump beam is still centered.
- Check if the diagnostic beam is still pre-aligned according to the green pump reflection.
- Check if all alignment apertures or pump block tools are open or removed.

- Use knob of the cavity length actuator (Fig. 5.4) to change the cavity length until the OPO is generating a signal. In case the diagnostic beam is sufficiently pre-aligned to be centered on PD2, the software "Search" routine of the cavity length actuator can be used alternatively.

- If signal generation is given check and correct the diagnostic beam alignment if necessary.

- Use the software to tune to 800 nm by pressing the "Set to Automatic" button.

- When tuning is finished (Status: Tuning OK), deactivate the automatic mode by pressing "Set to Manual" button.

- Press the "Correct offset" button of the cavity length actuator.

- Adjust M4 and M1 for maximum signal power on the externally placed power meter. Monitor the beam for good mode quality.

- Check and optimize the diagnostic beam alignment to PD2 and into the internal spectrometer.

- Check if all apertures are open or removed and close the two OPO covers.

- Open the pump shutter and the two hatches for external M1 and M4 alignment (see Fig. 5.21) to maximize signal power if necessary.

- Insert the externally measured signal power value in mW in the "Power Calibration" control for "Signal (mW)" in the SETUP menu.

The **Levante Emerald** OPO is now ready for automatic wavelength tuning.

Figure 5.21.: Alignment of M1 with covers closed. The M4 alignment can be done accordingly.

6. Wavelength Tuning

In this chapter the necessary preparation with respect to the software and a rough description of the tuning sequence and messages is given. However, the speed and robustness of the wavelength tuning also depends a lot on proper cavity alignment and the alignment of the diagnostic beam to the power photodiode and the internal spectrometer. Also, to prevent signal saturation of the spectrum measurement for high power configurations or a too weak spectrometer signal for standard or low power operation the flip-ND filter in front of the spectrometer has to be set accordingly.

6.1. Preconditions and Preparation

The following preconditions have to be fulfilled before automatic tuning is possible:

1. OPO software is started with the proper configuration file.
2. Pump beam is properly aligned into the OPO (see section 5.2) and the software detects the right pump power level within the specified range.
3. M2 mirror slide is fixed at the position calculated by the software (see Section 4.3.7 ”Show M2 position”).
4. ”Pump in” shutter is open.
5. Proper alignment of the OPO cavity and diagnostics beam as described in Chapter 5 is given.
6. All alignment apertures are removed or open.
7. OPO software is in ”Manual” tuning mode and status is ”idle”. The tuning mode button of GUI section 4 (see figure 4.3) shows ”Set to Automatic”.
8. OPO Signal generation can be started with the software buttons of the TUNING menu (GUI segment 3 of Figure 4.3):
   a) Insert the reference destination wavelength in the set wavelength control (GUI segment 4 of Figure 4.3): Signal [nm] = 800.
   b) Press the ”SET” button(s) for the OPO crystal temperature and the cavity length and wait until the actuator values arrive at their set points. (In case of the temperature control it can take several 10 seconds before the temperature is stabilized and the display of the current temperature switches to green.)

c) If the software does not show any OPO signal generation in the spectrum or signal power measurement the right cavity length can be found with the following alternatives:

   - In case the diagnostic beam path is sufficiently prealigned start the search function (press ”Search” button, see Section 4.3.5).
   - If diagnostic beam path alignment cannot be taken as granted, open the OPO and use the adjustment knob at the cavity length actuator module (see Figure 5.4). Keep in mind to override the interlock functionality that is activated if the cover is removed (refer to section 2.7.2). Move the cavity length slowly and watch for signs of signal generation as described in chapter 5. (Indication for signal generation are a sudden depletion in the green pump behind the OPO crystal or visible signal generation - if the signal set wavelength was chosen to be e.g. Signal [nm] = 750.)
   - Alternatively, one can also use the cavity length software control as described in Section 4.3.5.

9. The OPO will start to generate a signal around the set wavelength of 800 nm in this case.
10. If there is no signal spectrum displayed, open the OPO (pull out the interlock switches of the covers and re-open the input pump shutter) and optimize the diagnostic beam alignment to the internal spectrometer to monitor a signal spectrum.
11. Activate the ”Maximize Power” function of the Lyot-angle actuator to find the right Lyot order with the highest transmission.
12. Manually tune with the Lyot-filter arrow buttons to the 800 nm set wavelength and activate the ”Maximize Power” function of the cavity length actuator.
13. Optimize cavity alignment for maximum output power and good mode quality, see Chapter 5.
14. Check and optimize diagnostic beam alignment (i.e. alignment on the power photodiode and into the internal spectrometer) as described in Chapter 5.
15. Activate once more the ”Maximize Power” function of the cavity length.
16. After the power maximization routine has finished fine tune the signal wavelength to 800.0 nm with the Lyot-angle actuator and press ”Correct Offset” for the cavity length actuator.

Now the system is ready for automatic tuning and for using the sweep tuning function as described in section 4.3.6.

6.2. Levante Emerald Tuning

Automatic signal wavelength tuning of the **Levante Emerald** is possible between 660 nm and 950 nm for pump lasers centered around 516 nm. In case of a 532 nm pump laser the tuning range is shifted to longer wavelengths: 720 ... 990 nm.

Figure 6.1.: Software in "Automatic" tuning mode after successful wavelength tuning to 800 nm as displayed when "Show Actuators" option is selected.

The attempt to set a destination wavelength outside the allowed pump-dependent range generates the error message "set signal out of range". In this case the system remains at the former set wavelength.
Only a few steps are recommended to support a fast wavelength tuning:

1. Run the software in "Manual" tuning mode (tuning mode button is blue and shows "Set to Automatic").

2. Make sure the preconditions of Section 6.1 are fulfilled.

3. Insert the desired Signal or Idler wavelength in the Signal [nm] or Idler [nm] control respectively.

4. Press the tuning mode button. The button switches from blue to red and shows "Set to Manual". Also the status information changes from idle to tuning. Different tuning steps can be monitored:

   - in the additional status message given in brackets behind "tuning", or

- in the TUNING menu section: The change of the actuator position values (cavity or Lyot-angle actuator) and the measured crystal temperature is shown as well as the activation of the various automatic routines.

5. After successful tuning to the set wavelength the status displays ”tuning OK” and a cavity length stabilization routine is running to compensate for thermal drifts (see Figure 6.1).

6. The stabilization routine tries to correct a drop in signal power by adapting the cavity length. The limit to activate this correction can be monitored in the power stabilization section of the SETUP menu (see figure 4.3.3). It can be changed by the user if the box ”User Hysteresis” is checked. However, allowing larger drifts can lead to signal wavelength jumps into neighboring orders of the Lyot-filter. Wavelength deviations from the set value are recognized and corrected by Lyot fine tuning. (If an interaction of the software is unwanted, i.e. if stabilization measures are undesired the tuning mode should be switched to manual for a passive behavior of the system.)

7. The system remains in this state until:

   - A new set wavelength is inserted and confirmed by pressing ”Enter”. A new tuning is started.

   - Tuning mode is switched back to manual mode by the user.

   - ”Pump in” shutter is closed: The automatic tuning mode switches back to the manual mode.

   - Pump laser power drops below threshold: The software switches to ”Wait for pump” and restarts the tuning as soon as pump laser stabilizes within valid power limits.

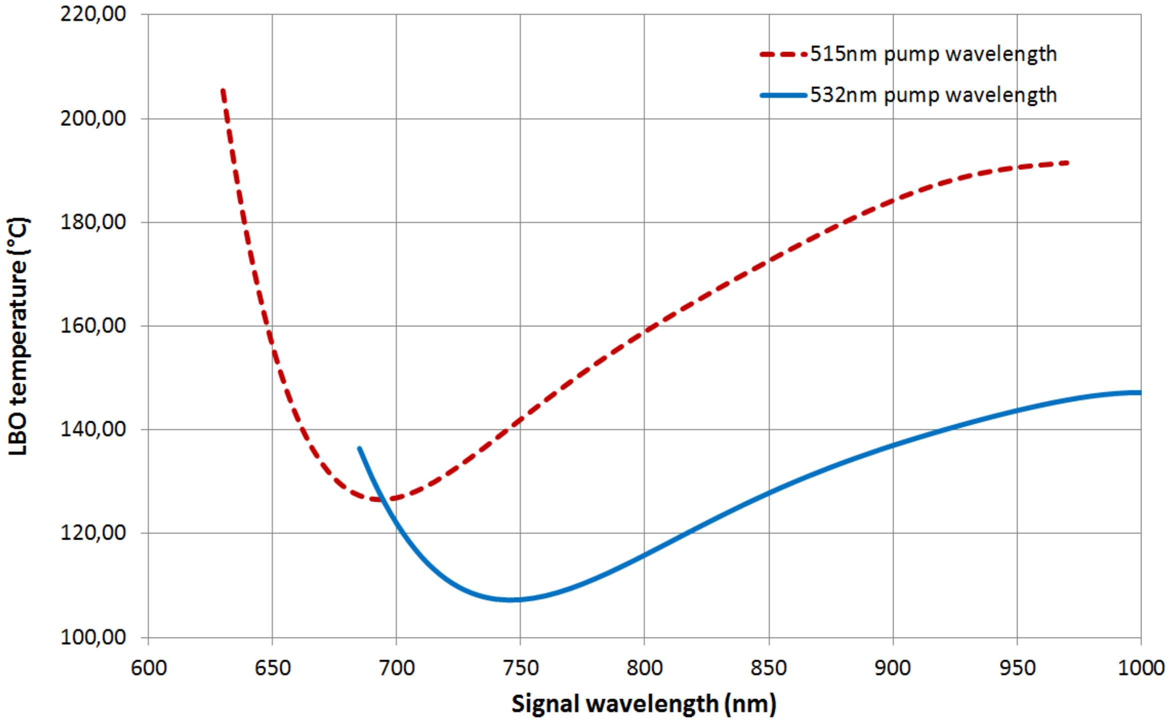


Figure 6.2.: Temperature phase-matching curves of the OPO crystal for two different pump wavelengths.

Levante Emerald Tuning Scheme

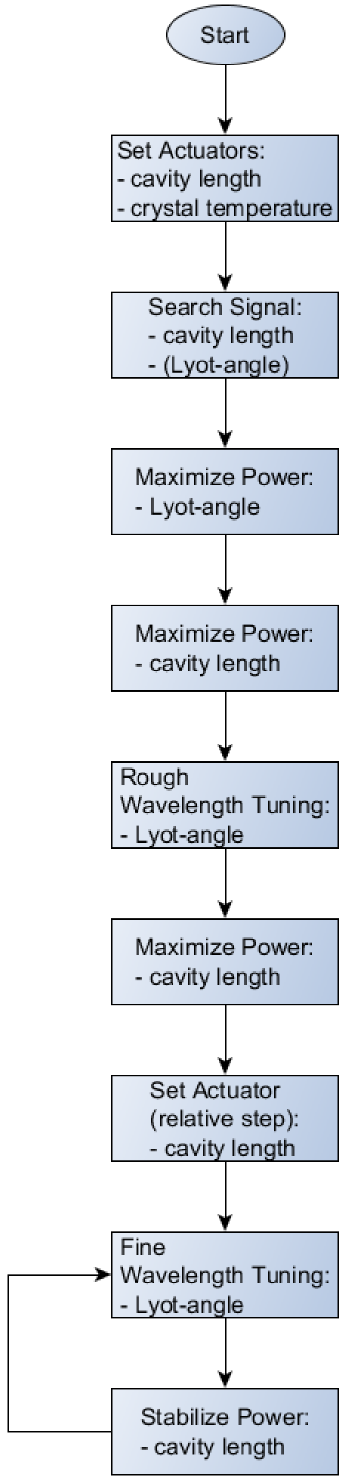


Figure 6.3.: Simplified **Levante Emerald** tuning scheme in case of successful completion of the individual functional subroutines.

A simplified scheme of the **Levante Emerald** tuning steps is depicted in figure 6.3. This procedure is started if

- the user presses the ”Set to Automatic” tuning mode button,
- the user enters a new value in the ”Signal [nm]” or ”Idler [nm]” control while the software is already in automatic tuning mode (tuning mode button showing ”Set to Manual”), or
- a tuning sweep is started.

In the following a short description for the different tuning steps is given:

1. **Start:** The input set wavelength is rechecked to lay within tuning range limits, the tuning is initialized.
2. **Set Actuators:**
    - The crystal phase-matching temperature is set to the calibrated value for the desired signal wavelength based on a calibrated curve as shown in figure 6.2.
    - The cavity length is set to an absolute position value (depending on a correct cavity length calibration offset: See ”Correct Offset” in figure 4.3.5) if no signal center wavelength is detected initially. If the OPO is already generating a signal a relative cavity length step is done.
    - The Lyot-angle actuator is centered within its travel range in case of a large relative wavelength step.
3. **Search Signal:** After all actuators arrived at their set points and no signal is detected, a search signal routine with the cavity length is started. For certain systems a search routine with the Lyot-angle actuator is started after unsuccessful search cavity routine in the short signal wavelength range.
4. **Maximize Power:** In case a signal is detected the search routine is omitted and power maximization routines are started:
    - The Lyot-angle actuator is scanned to find the Lyot-order with maximum signal power. This routine is omitted at long set signal wavelengths.
    - The cavity length is scanned to find the position of maximum power.
5. **Rough Lyot-angle Tuning:** The Lyot-angle actuator is used to tune the signal wavelength to the approximate set wavelength.
6. **Cavity-length fine correction:** With the signal close to the set wavelength a maximize power routine and a successive relative cavity length step prepares the correct cavity length for the set wavelength.

7. **Fine Lyot-angle Tuning:** A Lyot-angle fine tuning sets the measured signal center wavelength equal to the set wavelength with a tolerance of 0.1 nm.

8. **Stabilization:** After successful wavelength tuning the signal power value is monitored and compared to the one initially achieved. In case of a power drop below a certain tolerance threshold (refer to section 4.3.3) the stabilization routine tries to revive the initial power level. After successful stabilization the Lyot-angle fine tuning checks and corrects the signal wavelength. In case a wavelength jump is detected the tuning is set to restart.

These logic steps of signal wavelength tuning can also be used as a recipe for manual signal tuning by the user.

7. Theory of Optical Parametric Conversion and the Levante Emerald

An OPO uses a non-linear gain medium with a large second order susceptibility, χ^2, to convert a pump photon of high energy into two photons of lower energy. The parametric process is possible with CW, pulsed, or ultrafast pump sources and is peak power dependent. With the advent of reliable, high-powered mode-locked oscillators and high quality non-linear crystals, optical parametric oscillators (OPOs) are viable sources of widely tunable ultrafast light. The below is a short review of the physics of an optical parametric process.

The optical parametric down conversion process converts an input pump wave into two outputs, the Signal and Idler. For efficient energy transfer it is necessary that all three waves remain in phase, i.e. all three waves must propagate through the crystal at the same velocity. This implies that the index of refraction of the three waves is the same. Unfortunately, under most conditions, the normal dispersion of a crystal is such that the indices are different for the pump, Signal, and Idler beams. Luckily, dispersion can be offset by using the natural birefringence of uniaxial or biaxial crystals. These crystals have two refractive indices for a given direction of propagation, corresponding to the two allowed orthogonally polarized modes. By an appropriate choice of polarization and direction of propagation it is often possible to minimize the phase mismatch and even theoretically approach a zero mismatch. This is obviously termed phase matching (or to a lesser extent index matching).

Phase Matching

In general there are two distinct types of phase matching or techniques to satisfy the momentum conservation requirements. These techniques are referred to as type I (or parallel) and type II (or orthogonal) phase matching. The type of phase matching that is exploited depends on the crystalline structure and the orientation of the crystal with respect to the pump beam. In type I phase matching, the polarization vectors of the Signal and Idler are parallel and orthogonal to that of the pump. Whereas in the type II process the polarization vectors of the Signal and Idler are perpendicular to each other and the pump polarization vector is parallel to the Signal or Idler polarization vector. Moreover, when the propagation direction is along one of the principle axes of a crystal (such as the optic axis in an uniaxial, birefringent crystal), the phase matching is termed noncritical, while for any other direction it is referred to as critical phase matching. In general, noncritical phase matching has a wider acceptance angle which makes the process insensitive to small alignment deviations, insensitive to small temperature changes, and allows the usage of longer crystals which result in a higher conversion efficiency.

The above brief description leaves open the possibility of complete conversion of the fundamental beam to the Signal and Idler beam. In practice this is never realized. The conversion is limited by the pump beam divergence, the bandwidth of the pump beam, by angular and thermal deviations from the ideal phase matching conditions, various non-linear and saturation processes, and by a back conversion of the Signal and Idler to the pump.
By convention, the ”Signal” is defined by the higher frequency (shorter wavelength) of the two generated outputs. The frequency separating the Signal and Idler is called the degeneracy point and occurs at twice the pump wavelength. These frequencies must obey the following energy (or frequency or wavelength) and momentum conservation relations:

$$\nu_{\mathrm{p}} = \nu_{\mathrm{S}} + \nu_{\mathrm{I}} \tag{7.1}$$

$$\mathrm{n_p}\nu_{\mathrm{p}} = \mathrm{n_S}\nu_{\mathrm{S}} + \mathrm{n_I}\nu_{\mathrm{I}}, \tag{7.2}$$

where ν refers to a frequency, n refers to an index of refraction, and the subscripts refer to pump, signal, and idler. It is often convenient to express eq. 7.1 in terms of the wavelength (λ) of the three beams:

$$1/\lambda_{\mathrm{p}} = 1/\lambda_{\mathrm{S}} + 1/\lambda_{\mathrm{I}}. \tag{7.3}$$

Tuning of Bulk Crystal OPOs

The momentum conservation (or phase-match, see eq. 7.2) condition noted above is the mechanism that is used to wavelength-tune an OPO. Tuning can be accomplished by altering the refractive indices of the medium along the direction of propagation through rotation of the crystal (angle-tuning), changing its temperature (temperature-tuning), or by applying an electric field to the material (electro-optic tuning).

Laser, Oscillator, Amplifier ...

An optical parametric system can be configured into one of two basic setups. If the optical cavity is designed as a single pass (i.e., only one pulse is in the crystal at any given time) then the system is termed an Optical Parametric Amplifier (OPA). In case the nonlinear crystal is placed into a resonator, the threshold of the nonlinear process is strongly reduced. Such a system is termed Optical Parametric Oscillator (OPO). If the optical cavity is designed to be synchronized with the pump source the system is termed a synchronously pumped Optical Parametric Oscillator. The OPO is synchronized

if the round trip time of the pulses in the OPO cavity is the same as the pulse repetition rate of the pump laser. This presence, or resonance, allows for an “optical gain”. The synchronization, or the build-up of the parametric waves, is absolutely necessary for a low threshold synchronously pumped OPO. An OPO is termed signal resonant if the cavity is designed to support the resonance of the signal beam, idler resonant if it is designed to support the idler beam.
In either of the above categories, the system is technically not a laser, even though they are sometimes referred to as a laser. A laser has the unique characteristic of energy storage, which is not present in an OPA or OPO. Conventional laser sources have an optical gain due to the energy storage that results from a population inversion. In a parametric process, gain is provided through the simultaneous presence and interaction of the optical fields in a crystal with a non-zero second order susceptibility χ^2.

Levante Emerald OPO

The **Levante Emerald** is an optical parametric oscillator that is synchronously pumped by the SHG of a modelocked ps-Nd:VAN or Yb-fiber laser (i.e. at a wavelength of 532 nm or 515 nm respectively). It is based on collinear, type I non-critically phase-matched parametric interaction in LBO. The cavity mirrors are designed for a high reflectivity of the signal beam making the system a signal resonant OPO. The wavelength tuning mechanism is based on a rough selection of the wavelength via temperature phase-matching in the LBO and fine selection via Lyot-filter and cavity length.

8. CARS Microscopy

The **Levante Emerald** is the ideal light source for CARS microscopy! You can use signal and idler from the **Levante Emerald** OPO as pump and stokes beam. The two wavelengths come out of the same exit port and are overlapped perfectly in space and time. Thus no timing jitter and spatial mismatch arise, and the beam can be sent directly into the microscope. A CARS wavelength tuning curve is shown in Fig. 8.1.

Please note: In this operation the Levante Emerald generates CARS signals itself on the surfaces of the OPO-crystal. When using it for CARS microscopy you need an appropriate long pass filter to block the generated CARS wavelengths (See Fig. 8.1 and 8.2).

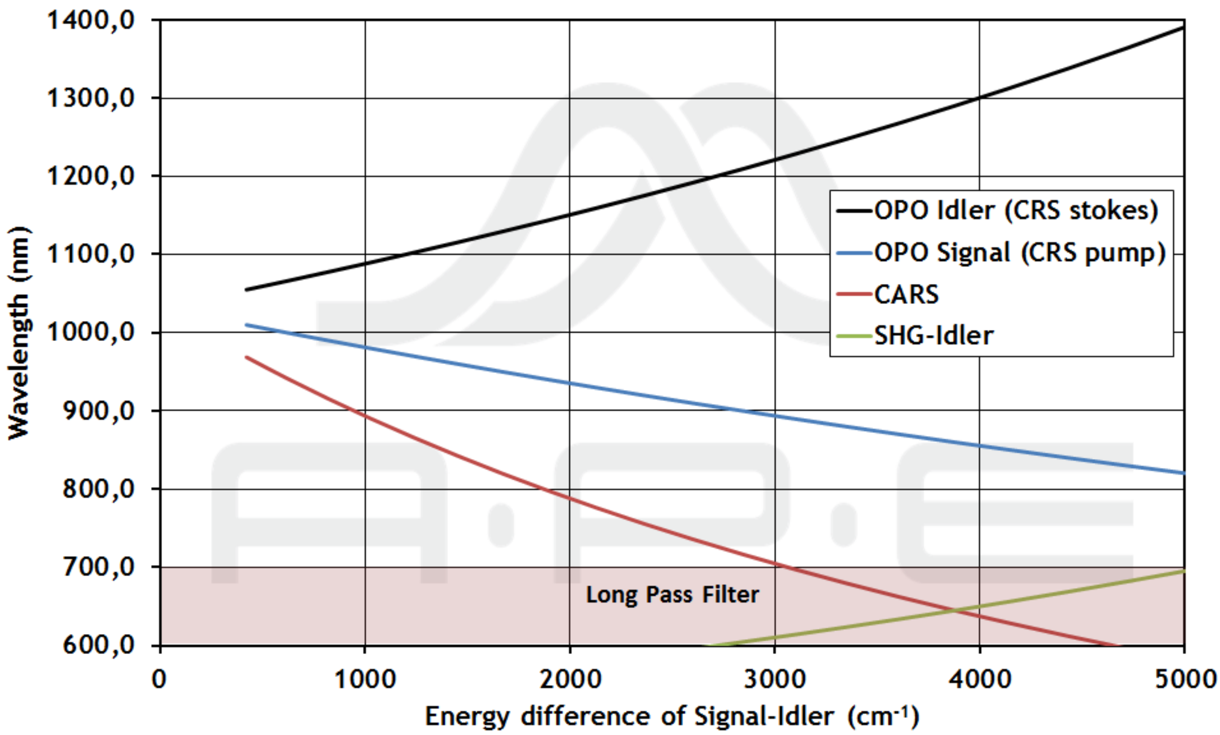


Figure 8.1.: CARS wavelengths for **Levante Emerald** signal wavelengths as pump and idler as stokes for the respective vibrational frequencies. The **Levante Emerald** OPO is pumped at 516 nm.

For the combination of signal and 1032 nm pump (1032 nm is always accessible from the pump laser via an integrated variable beam splitter), a tuning curve is shown in Fig. 8.2.

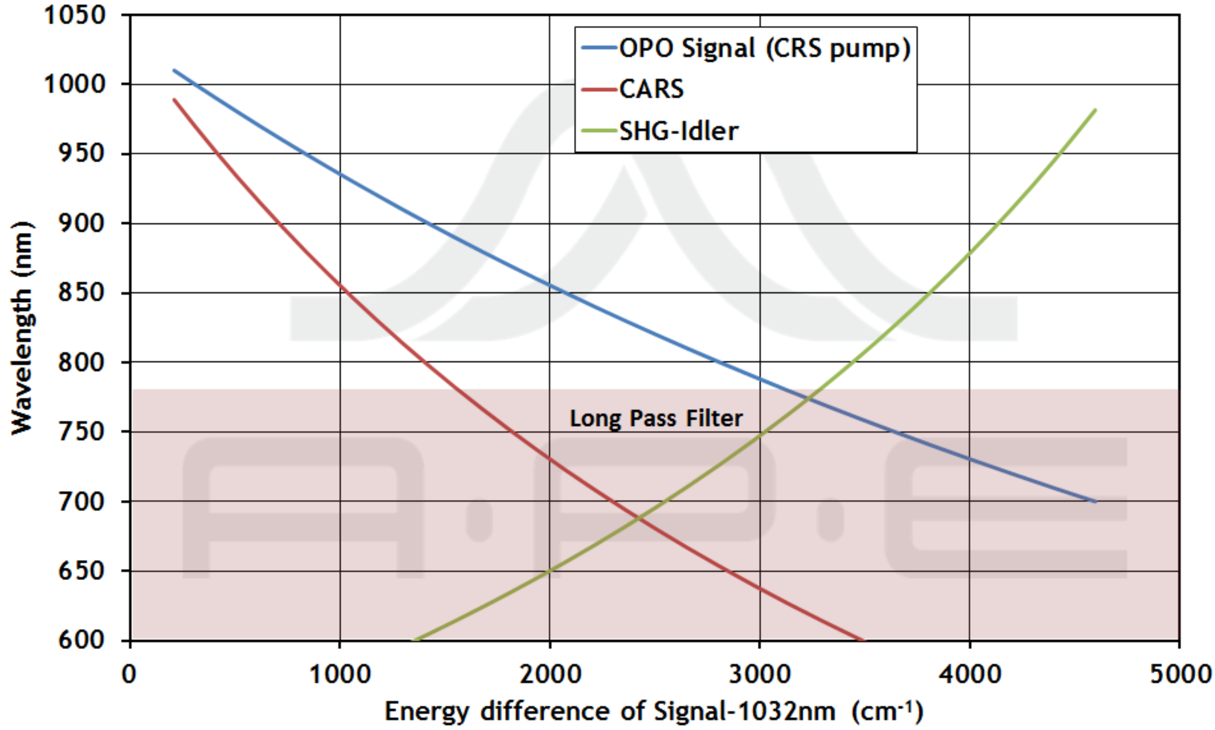


Figure 8.2.: CARS wavelengths for **Levante Emerald** signal wavelengths as pump and 1032 nm as stokes for the respective vibrational frequencies. The **Levante Emerald** OPO is pumped at 516 nm.

A. Appendix

A.1. Table of TCP/IP-commands

To control the OPO from remote via TCP/IP the host name (or IP address) of the computer where the software runs has to be known, a designated port number has to be chosen and the TCP/IP server of the OPO software must be started (See FILE menu in section 4.3.1).
Please, make sure that the specific TCP port number is not blocked by the firewall of the controller PC.

A.1.1. Lyot-Actuator Commands

SET_LYOT<position>

Set lyot position

<position>	integer, range: 0 ... 10000 New Lyot-acutator set position

Example:

```
set_lyot=5000
```

SET_LYOT?

Get lyot position

<position>	integer, range: 0 ... 10000 Current Lyot-acutator set position

Example:

```
set_lyot?
```

SET_LYOT_STEPLENGTH1<steplength>

Set lyot step length 1

<steplength>	integer New Lyot-actuator step length 1

Example:

```
set_lyot_steplength1=10
```

SET_LYOT_STEPLENGTH1?

Get lyot step length 1
<steplength> integer
Current Lyot-actuator step length 1

Example:

```
set_lyot_steplength1?
```

SET_LYOT_STEPLENGTH2<steplength2>

Set lyot step length 2
<steplength2> integer
New Lyot-actuator step length 2

Example:

```
set_lyot_steplength2=10
```

SET_LYOT_STEPLENGTH2?

Get lyot step length 2
<steplength2> integer
Current Lyot-actuator step length 2

Example:

```
set_lyot_steplength2?
```

STEP_LYOT_DEC1

Decrement lyot position by step length 1

Example:

```
step_lyot_dec1
```

STEP_LYOT_DEC2

Decrement lyot position by step length 2

Example:

```
step_lyot_dec2
```

STEP_LYOT_INC1

Increment lyot position by step length 1

Example:

```
step_lyot_inc1
```

STEP_LYOT_INC2

Increment lyot position by step length 2

Example:

```
step_lyot_inc2
```

LYOT_POSITION?

Get the position of lyot actuator

<position>	integer Current position of lyot actuator

Example:

```
lyot_position?
```

LYOT_BUSY?

Get busy state of lyot actuator

<state>	boolean Current state of lyot-actuator; 0,F,FALSE = actuator idle, 1,T,TRUE = actuator busy/moving

Example:

```
lyot_busy?
```

A.1.2. Cavity-Length Actuator Commands

SET_CAVITY_LAMBDA

Set cavity actuator to the calibrated position for the set signal wavelength

Example:

```
set_cavity_lambda
```

CORRECT_CAVITY_OFFSET

Correct the offset of the position calibration of the cavity actuator with respect to the measured signal wavelength

Example:

```
correct_cavity_offset
```

SET_CAVITY<position>

Set cavity position (agilis)

<position> integer, range: 200000 ... 2000000
New cavity actuator set position

Example:

```
set_cavity=1000000
```

SET_CAVITY?

Get cavity set position (agilis)

<position> integer, range: 200000 ... 2000000
Current cavity actuator set position

Example:

```
set_cavity?
```

SET_CAVITY_FULLSTEPS<steps>

Set cavity full steps (agilis)

<steps> integer
New number of full steps for cavity actuator

Example:

```
set_cavity_fullsteps=10
```

SET_CAVITY_FULLSTEPS?

Get cavity full steps (agilis)

<steps> integer
Current number of full steps for cavity actuator

Example:

```
set_cavity_fullsteps?
```

SET_CAVITY_SUBSTEPS<steps>

Set cavity sub steps (agilis)

<steps> integer
New number of sub steps for cavity actuator

Example:

```
set_cavity_substeps=1
```

SET_CAVITY_SUBSTEPS?

Get cavity sub steps (agilis)

<steps> integer
Current number of sub steps for cavity actuator

Example:

```
set_cavity_substeps?
```

FULL_DEC_CAVITY

Decrement cavity position by current number of full steps

Example:

```
full_dec_cavity
```

SUB_DEC_CAVITY

Decrement cavity position by current number of sub steps

Example:

```
sub_dec_cavity
```

FULL_INC_CAVITY

Increment cavity position by current number of full steps

Example:

```
full_inc_cavity
```

SUB_INC_CAVITY

Increment cavity position by current number of sub steps

Example:

```
sub_inc_cavity
```

CAVITY_POSITION?

Get the position of cavity actuator
<position> integer
Current position of cavity actuator (agilis)

Example:

```
cavity_position?
```

CAVITY_BUSY?

Get busy state of cavity actuator
<state> boolean
Current state of cavity actuator (agilis); 0,F,FALSE = actuator idle, 1,T,TRUE = actuator busy/moving

Example:

```
cavity_busy?
```

A.1.3. Crystal-Heater Commands

SET_TEMP_LAMBDA

Set phase-matching temperature to the calibrated value for the set signal wavelength

Example:

```
set_temp_lambda
```

SET_XTAL_TEMPERATURE<temp>

Set the crystal temperature in degree C
<temp> double, range: 90 ... 220
Crystal set temperature in degree C

Example:

```
set_xtal_temperature=150
```

SET_XTAL_TEMPERATURE?

Get the crystal temperature in degree C
<temp> double, range: 90 ... 220
Crystal set temperature in degree C

Example:

```
set_xtal_temperature?
```

XTAL_TEMPERATURE?

Get the measured crystal temperature in degree C
<temp> double
Current crystal temperature in degree C

Example:

```
xtal_temperature?
```

XTAL_TEMP_STABILIZED?

Get state of the measured crystal temperature
<state> boolean
Status of crystal temperature; 0,F,FALSE = not stabilized, 1,T,TRUE = stabilized at set value

Example:

```
xtal_temp_stabilized?
```

THERMO_STATUS?

Get operation state of heater module
<state> integer

Example:

```
thermo_status?
```

THERMO_DURATION?

Get speed of heater
<speed> integer

Example:

```
thermo_duration?
```

A.1.4. Beam Shutter Commands

PUMP_OPEN<state>

Set state of the pump shutter
<state> boolean
New state of the pump-shutter; 1,T,TRUE = open, 0,F,FALSE = close

Example:

```
pump_open=TRUE
```

PUMP_OPEN?

Get state of the pump shutter
<state> boolean
Current state of the pump-shutter; 1,T,TRUE = open, 0,F,FALSE = closed

Example:

```
pump_open?
```

OUTPUT_OPEN<state>

Set state of the output shutter (for signal and idler)
<state> boolean
New state of the output-shutter; 1,T,TRUE = open, 0,F,FALSE = close

Example:

```
output_open=TRUE
```

OUTPUT_OPEN?

Get state of the output shutter (for signal and idler)
<state> boolean
Current state of the output-shutter; 1,T,TRUE = open, 0,F,FALSE = closed

Example:

```
output_open?
```

A.1.5. Tuning Set-Parameter Commands

SET_SIGNAL_WAVELENGTH<sig_wl>

Set the new signal wavelength
<sig_wl> double, range: 630 ... 1000
Set signal wavelength in nm

Example:

```
set_signal_wavelength=800.4
```

SET_SIGNAL_WAVELENGTH?

Get the set signal wavelength
<sig_wl> double, range: 630 ... 1000
Set signal wavelength in nm

Example:

```
set_signal_wavelength?
```

SET_IDLER_WAVELENGTH<idler_wl>

Set the new idler wavelength

<idler_wl> double, range: 1100 ... 2700
Set idler wavelength in nm

Example:

```
set_idler_wavelength=2000
```

SET_IDLER_WAVELENGTH?

Get the set idler wavelength

<idler_wl> double, range: 1100 ... 2700
Set idler wavelength in nm

Example:

```
set_idler_wavelength?
```

AUTOMATIC<state>

Set new state of the automatic tuning function

<state> boolean
Status of automatic tuning mode; 0,F,FALSE = stop automatic tuning routine (set to manual tuning), 1,T,TRUE = activate automatic tuning routine

Example:

```
automatic=TRUE
```

AUTOMATIC?

Get the state of the automatic tuning function

<state> boolean
Status of automatic tuning mode; 0,F,FALSE = manual tuning, 1,T,TRUE = automatic tuning routine active

Example:

```
automatic?
```

A.1.6. Pump-Parameter Commands

PUMP_WAVELENGTH<pump_wl>

Set the wavelength of the pump laser
<pump_wl> double, range: 510 ... 540
Pump laser center wavelength in nm

Example:

```
pump_wavelength=515.6
```

PUMP_WAVELENGTH?

Get the set wavelength of the pump laser
<pump_wl> double, range: 510 ... 540
Pump laser center wavelength in nm

Example:

```
pump_wavelength?
```

REPETITIONRATE<reprate>

Set the repetitionrate of the pump laser
<reprate> integer
Pump laser repetitionrate in Hz

Example:

```
repetitionrate=80000000
```

REPETITIONRATE?

Get the set repetitionrate of the pump laser
<reprate> integer
Pump laser repetitionrate in Hz

Example:

```
repetitionrate?
```

A.1.7. Automatic Subroutines Commands

SEARCH_SIGNAL<state>

Start/stop search signal routine (uses cavity length actuator)
<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
search_signal=TRUE
```

SEARCH_SIGNAL?

Get the status of the search signal routine (uses cavity length actuator)
<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
search_signal?
```

SEARCH_SIGNAL_LYOT<state>

Start/stop search signal routine (uses Lyot actuator)
<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
search_signal_lyot=TRUE
```

SEARCH_SIGNAL_LYOT?

Get the status of the search signal routine (uses Lyot actuator)
<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
search_signal_lyot?
```

MAX_POWER_LYOT<state>

Start/stop automatic maximization of the output power (uses Lyot actuator)
<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
max_power_lyot=TRUE
```

MAX_POWER_LYOT?

Get the current state of power maximization routine (uses Lyot actuator)
<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
max_power_lyot?
```

MAX_PEAK_LYOT<state>

Start/stop automatic maximization of the spectrums' peak-value (uses Lyot actuator)

<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
max_peak_lyot=TRUE
```

MAX_PEAK_LYOT?

Get the current state of peak maximization routine (uses Lyot actuator)

<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
max_peak_lyot?
```

MAX_POWER_CAVITY<state>

Start/stop automatic maximization of the output power (uses cavity position actuator)

<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
max_power_cavity=TRUE
```

MAX_POWER_CAVITY?

Get the current state of power maximization routine (uses cavity position actuator)

<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
max_power_cavity?
```

MAX_PEAK_CAVITY<state>

Start/stop automatic maximization of the spectrums' peak-value (uses cavity position actuator)

<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
max_peak_cavity=TRUE
```

MAX_PEAK_CAVITY?

Get the current state of peak maximization routine (uses cavity position actuator)

<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
max_peak_cavity?
```

A.1.8. Automatic Stabilization Commands

STABILIZE_CAVITY<state>

Start/Stop cavity length stabilisation routine

<state> boolean
Status of routine; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
stabilize_cavity=TRUE
```

STABILIZE_CAVITY?

Get the current state of cavity length stabilisation routine

<state> boolean
Status of routine; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
stabilize_cavity?
```

STABILIZE_ACTIVE?

Get the mode of cavity length stabilisation routine

<state> boolean
Mode of routine; 0,F,FALSE = stabilization passive, 1,T,TRUE = stabilization active

Example:

```
stabilize_active?
```

STABILIZE_POWER_ACTIVE<state>

Set the new state of power stabilisation option

<state> boolean
Status of routine; 0,F,FALSE = disable power stabilization option, 1,T,TRUE = enable power stabilization option

Example:

```
stabilize_power_active=TRUE
```

STABILIZE_POWER_ACTIVE?

Get the state of power stabilisation option

<state> boolean
Status of routine; 0,F,FALSE = power stabilization option disabled, 1,T,TRUE = power stabilization option enabled

Example:

```
stabilize_power_active?
```

STABILIZE_TOLERANCE_LAMBDA<tolerance>

Set custom tolerance for wavelength stabilization

<tolerance> double, unit: nm
Wavelength stabilization tolerance in nm for the routine to switch between passive and active mode

Example:

```
stabilize_tolerance_lambda=0.5
```

STABILIZE_TOLERANCE_LAMBDA?

Get currently used tolerance value for wavelength stabilization

<tolerance> double, unit: nm
Wavelength stabilization tolerance in nm for the routine to switch between passive and active mode

Example:

```
stabilize_tolerance_lambda?
```

STABILIZE_TOLERANCE_POWER<tolerance>

Set custom tolerance for power stabilization

<tolerance> double, unit: percent
Power stabilization tolerance in percent of initial maximum power for the routine to switch between passive and active mode

Example:

```
stabilize_tolerance_power=5
```

STABILIZE_TOLERANCE_POWER?

Get currently used tolerance value for power stabilization

<tolerance> double, unit: percent
Power stabilization tolerance in percent of initial maximum power for the routine to switch between passive and active mode

Example:

```
stabilize_tolerance_power?
```

ACTIVATE_USER_TOLERANCE_LAMBDA<status>

Set value for ”Use custom tolerance value for wavelength stabilization”

<status> boolean
Status of option; 0,F,FALSE = deactivate custom tolerance, 1,T,TRUE = activate custom tolerance

Example:

```
activate_user_tolerance_lambda=TRUE
```

ACTIVATE_USER_TOLERANCE_LAMBDA?

Get value of ”Use custom tolerance value for wavelength stabilization”

<status> boolean
Status of option; 0,F,FALSE = custom tolerance not used, 1,T,TRUE = custom tolerance used

Example:

```
activate_user_tolerance_lambda?
```

ACTIVATE_USER_TOLERANCE_POWER<status>

Set value for ”Use custom tolerance value for power stabilization”

<status> boolean
Status of option; 0,F,FALSE = deactivate custom tolerance, 1,T,TRUE = activate custom tolerance

Example:

```
activate_user_tolerance_power=TRUE
```

ACTIVATE_USER_TOLERANCE_POWER?

Get value of "Use custom tolerance value for power stabilization"

<status> boolean

Status of option; 0,F,FALSE = custom tolerance not used, 1,T,TRUE = custom tolerance used

Example:

```
activate_user_tolerance_power?
```

A.1.9. Set/Get Power Value Commands

PUMP_POWER<power>

Set a power value (in mW) for pump power re-calibration

<power> integer

Pump power in mW value for calibration correction

Example:

```
pump_power=1234
```

PUMP_POWER?

Get the power of the input pump beam

<power> integer

Measured power of the input pump beam in mW

Example:

```
pump_power?
```

PUMP_POWER_RAW?

Get the raw value of the power measurement of the input pump beam

<power> integer

Example:

```
pump_power_raw?
```

SIGNAL_POWER<power>

Set a power value (in mW) for signal power re-calibration

<power>	integer
	Signal power in mW value for calibration correction

Example:

```
signal_power=1234
```

SIGNAL_POWER?

Get the raw value of the power measurement of the output signal

<power>	integer
	Measured power of the output signal beam in mW

Example:

```
signal_power?
```

SIGNAL_POWER_RAW?

Get the raw value of the power measurement of the output signal beam

<power>	integer

Example:

```
signal_power_raw?
```

A.1.10. Get Wavelength and Spectrum Information Commands

SIGNAL_WAVELENGTH?

Get the center wavelength of the measured signal spectrum

<wl>	double
	Measured wavelength of the signal output in nm

Example:

```
signal_wavelength?
```

IDLER_WAVELENGTH?

Get the calculated center wavelength of the generated idler from the measured signal wavelength

<wl>	double
	Calculated wavelength of the idler output in nm

Example:

```
idler_wavelength?
```

BANDWIDTH?

Get the FWHM bandwidth in nm of the measured signal spectrum

<bw> double

Measured bandwidth of the signal output in nm

Example:

```
bandwidth?
```

SPECTRUM?

Get the measured signal spectrum

<spec> string

Measured spectrum data as SCPI Block data. Data is formatted as double values and stored as interleaved array [X0,Y0,X1,Y1,...,Xn,Yn]

Example:

```
spectrum?
```

SPECTRUM_BINARY?

Get the measured signal spectrum as binary data

<spec> array of s in block data format

Measured spectrum as binary data

Example:

```
spectrum_binary?
```

A.1.11. Get State / OPO Parameter Commands

TEMPERATURE?

Get the temperature in degree C

<temp> double

Measured temperature in degree C inside the OPO optical unit

Example:

```
temperature?
```

HUMIDITY?

Get humidity value in percent

<humidity> double

Measured humidity in percent inside the OPO optical unit

Example:

```
humidity?
```

SLIDE_POSITION?

Get position of the M2 mirror slider
<position> integer
Calculated position of the M2 mirror slider

Example:

```
slide_position?
```

INTERLOCK?

Get state of the interlock
<state> boolean
Status of the interlock; 0,F,FALSE = not activated, 1,T,TRUE = activated

Example:

```
interlock?
```

STATE?

Get the opo state
<state> string
OPO state

Example:

```
state?
```

A.1.12. Parameter Logging Commands

LOG_PARAMETERS_USER

Save the current OPO parameter values (e.g. crystal/cavity position, temperature, ...) to the logfile

Example:

```
log_parameters_user
```

LOG_PARAMETERS_TUNING<status>

Enable/Disable automatic logging of OPO parameter values when tuning was successful

<status> boolean
Set status of the option; 0,F,FALSE = deactivate, 1,T,TRUE = activate

Example:

```
log_parameters_tuning=TRUE
```

LOG_PARAMETERS_TUNING?

Get status of automatic parameter logging option after successful tuning
<status> boolean
Get status of the option; 0,F,FALSE = not activated, 1,T,TRUE = activated

Example:

```
log_parameters_tuning?
```

LOG_INTERVAL<status>

Set time inverval in seconds for cyclic parameter logging
<status> double, range: 0.1 ... 3600

Example:

```
log_interval=10
```

LOG_INTERVAL?

Get the current time interval in seconds for parameter logging
<status> double, range: 0.1 ... 3600

Example:

```
log_interval?
```

LOG_PARAMETERS_TIMED<status>

Enable/Disable periodic logging of OPO parameter values
<status> boolean
Set status of the option; 0,F,FALSE = deactivate, 1,T,TRUE = activate

Example:

```
log_parameters_timed=TRUE
```

LOG_PARAMETERS_TIMED?

Get status of periodic parameter logging option

<status> boolean
Get status of the option; 0,F,FALSE = not activated, 1,T,TRUE = activated

Example:

```
log_parameters_timed?
```

A.1.13. SWEEP Tuning Commands

SWEEP_WL_START<sig_wl>

Set the start signal wavelength for the sweep tuning.

<sig_wl> double, range: 630 ... 1000
Start signal wavelength in nm

Example:

```
sweep_wl_start=700.4
```

SWEEP_WL_START?

Get the start signal wavelength for the sweep tuning.

<sig_wl> double, range: 630 ... 1000
Start signal wavelength in nm

Example:

```
sweep_wl_start?
```

SWEEP_WL_STOP<sig_wl>

Set the stop signal wavelength for the sweep tuning.

<sig_wl> double, range: 630 ... 1000
Stop signal wavelength in nm

Example:

```
sweep_wl_stop=710.4
```

SWEEP_WL_STOP?

Get the stop signal wavelength for the sweep tuning.

<sig_wl> double, range: 630 ... 1000
Stop signal wavelength in nm

Example:

```
sweep_wl_stop?
```

SWEEP_WL_STEP<wl_step>

Set the wavelength step length for the sweep tuning.

<wl_step> double, range: 0.1 ... 5
Signal wavelength step in nm

Example:

```
sweep_wl_step=1.5
```

SWEEP_WL_STEP?

Get the wavelength step length for the sweep tuning.

<wl_step> double, range: 0.1 ... 5
Signal wavelength step in nm

Example:

```
sweep_wl_step?
```

SWEEP_SAMPLES<sweep_smpl>

Set the number of wavelength samples.

<sweep_smpl> integer, range: 1 ... 1500
Numer of signal wavelengths set for the sweep tuning

Example:

```
sweep_samples=10
```

SWEEP_SAMPLES?

Get the number of wavelength samples.

<sweep_smpl> integer, range: 1 ... 1500
Numer of signal wavelengths set for the sweep tuning

Example:

```
sweep_samples?
```

SWEEP_HOLD<hold_time>

Set the hold time at each set wavelength.

<hold_time> integer, range: 1 ... 3600
Hold time at each signal wavelength in seconds

Example:

```
sweep_hold=5
```

SWEEP_HOLD?

Get the hold time at each set wavelength.

<hold_time> integer, range: 1 ... 3600
Hold time at each signal wavelength in seconds

Example:

```
sweep_hold?
```

SWEEP_HOLD_TIME?

Get the current time already in hold for the set wavelength.

<hold_time> double
Current length of stay at the present signal wavelength of the sweep tuning routine in seconds

Example:

```
sweep_hold_time?
```

SWEEP<state>

Start/stop of the sweep tuning function

<state> boolean
Status of the sweep tuning; 0,F,FALSE = stop routine, 1,T,TRUE = start routine

Example:

```
sweep=TRUE
```

SWEEP?

Get the state of the sweep tuning function

<state> boolean
Status of the sweep tuning; 0,F,FALSE = disabled, 1,T,TRUE = active

Example:

```
sweep?
```

SWEEP_TRIGGER

Starts the tuning step to the next signal wavelength.

Example:

```
sweep_trigger
```

SWEEP_WL?

Get the current set wavelength of the sweep tuning routine.
<wl> double
Current or next signal wavelength of the sweep tuning routine

Example:

```
sweep_wl?
```

A.2. List of Status informations

A.2.1. ”Manual tuning mode”

Status message	**Description**
idle	software is ready for input
Warning	system is not ready for tuning (check interlock and pump laser)
Shutter init	pump shutter cannot be opened due to initialization period of 120 sec
Shutter closed	Pump shutter was closed
Interlock active	Pump shutter was closed due to interlock

A.2.2. ”Automatic tuning mode”

tuning init	Tuning routine is initializing
tuning (temp set)	Crystal temperature is set
tuning (cavity set)	Cavity length actuator is set
tuning (lyot set)	Lyot angle actuator is set
tuning (lyot rough)	Wavelength tuning to set value with rough success tolerance
tuning (lyot fine)	Wavelength tuning to set value with smallest success tolerance
tuning (search)	Cavity length actuator is moved to search for OPO signal
tuning (search lyot)	Lyot angle actuator is turned to search for OPO signal
tuning (max power lyot)	Power maximization with Lyot angle actuator
tuning (max peak lyot)	Spectrometer peak maximization with Lyot angle actuator
tuning (max power cavity)	Power maximization with cavity length actuator
tuning (max peak cavity)	Spectrometer peak maximization with cavity length actuator
tuning OK	Tuning is successfully finished at set wavelength
stabilizing	Cavity length stabilization to hold wavelength and power
Warning: Wait for pump	Automatic tuning mode waits for stable and valid pump parameters to restart the tuning
restart (due to error)	Complete tuning routine is restarted (possible reasons: subroutine was unsuccessful / pump laser parameters deviate from start conditions)
Sweep init	Initialization of sweep tuning routine: Standard tuning to start wavelength of the sweep.
Sweep tuning	Actuators (crystal temperature, cavity length and Lyot angle) are set for the next signal wavelength.
Sweep hold	Sweep routine waits at a reached signal wavelength for a trigger or hold timeout to continue the wavelength sweep.
Sweep stop	Sweep routine is finished and stopped.
Sweep error	Sweep routine is stopped prematurely due to an error

Error messages (subroutines)

error (cavity set)	Set command was not executed
error (search)	Search routine with cavity length actuator stopped unsuccessfully
error (search lyot)	Search routine with Lyot angle actuator stopped unsuccessfully
error (max power lyot)	Maximization routine stopped without success (possible reasons: actuator reached limit / detector shows overload / determined max signal position shows low signal)
error (max peak lyot) error (max power cavity) error (max peak cavity)	
error (lyot rough)	Wavelength tuning routine with Lyot angle actuator stopped unsuccessfully
error (lyot fine)	
error (stabilization)	Stabilization routine stopped (possible reasons: actuator reached limit / detector shows overload / signal dropped to low power)

Error messages

error (set signal out of range)	Inserted set wavelength is outside the accessible range. The last valid set wavelength is kept.
error (pump)	Measured pump power is too low / no pump detected.
error (shutter closed)	Pump in shutter closed during tuning process
error (thermo set to standby)	SHG crystal thermostat is set to standby temperature (possible reasons: missing watchdog command / module error)
error (thermo: no heating)	Heating is impossible (module error)
error (thermo)	Heating is impossible (possible reasons: crystal mount unplugged / module error)

A.3. Scope of Delivery

Optics:

- Optics unit / OPO assembly
- Optics set for OPO (partly mounted)
- Pump optics set

Electronics and Cables:

- Power cord EU, UK, or US depending on country
- Power supply
- Cable USB A - USB B (2 m)
- Interlock jumper
- Grounding cable

Tools:

- **APE**laser beam shield
- Foot clamps (2x 120 mm, 1x 250 mm)
- Hex key (2.5 mm)
- Mirror key
- Infrared sensor card
- Alignment apertures (1x magnetic fix position, 1x magnetic free positionable)
- Beam block tool

Other:

- Tubing and connectors for purging
- Posts and mounts for 2 pump beam mirrors
- Pump beam tubing
- Controller notebook with installed software
- Packing list
- This manual

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