REDBACK SYSTEMS

RS40k Echelle Spectrometer

User Manual

Version 1.5 - July 7, 2023

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1. Introduction

Thank you for purchasing a Redback Systems product. This manual provides you with directions on the device installation and operation as well as a brief introduction to the RedSolve software. Please read the following instructions carefully.

> <u>NOTE</u>: Please read this manual carefully before installing and operating your new RS40k spectrometer. It is important to understand and follow all safety, installation, operation, and maintenance procedures as stated to ensure proper functionality.

2. Requirements

To ensure your computer can operate the device software and drivers, please read the hardware and software system requirements below. Note that at this time only the Windows operating system is supported. In addition to hardware requirements, an internet connection is required for downloading the device driver, software and manual.

Minimum hardware and software requirements:

- Operating System: Windows 10 (64 bit)
- Processor: Intel Core i5 or AMD Ryzen 5
- USB 2.0 port
- RAM: 8.0 GB
- HDD: 256 GB internal hard drive

Recommended hardware and software requirements:

- Operating System: Windows 10 (64 bit)
- Processor: Intel Core i7 or AMD Ryzen 7
- USB 3.0 high speed port (preferred)
- RAM: 16.0 GB RAM
- HDD: 1TB internal SSD hard drive

3. Warnings

- Your Redback Systems spectrometer is a precision optical instrument. Always handle it with the level of care appropriate for such instruments.

- There are no user serviceable parts inside the spectrometer housing or inside the camera. Subsequently, both components **MUST NOT** be opened.

- Care should be taken such that the camera does not overheat. The camera's air vents must not be blocked.

- Your Redback Systems spectrometer does not contain a shutter. Please avoid illuminating the detector with high-power lasers.

4. Safety Precautions

4.1 General Handling

- Handle the spectrometer with care.
- Make sure the spectrometer is placed on a flat surface with its red lid at the top.
- Do not operate in damp or wet conditions with RH >70%.
- Do not use the spectrometer in an outdoor environment.
- Do not disassemble the spectrometer or attempt to modify or repair it.
- Do not subject the spectrometer to mechanical shock or vibration.
- Do not cover the cooled detector.
- Do not operate the spectrometer in explosive environments.
- Only use the electrical cables provided.
- Avoid static electricity.

4.2 Fibre Installation

- Take care when installing the optical fibre.
- Only use FC/PC fibre connectors as specified in Section 5.3 of this manual.

5. Installation

5.1 Contents of Shipment

Please inspect the device mechanically and unpack the contents in a clean, dry, and EDS-free area. Verify that you have received the following items with the package:

- RS40k spectrometer in Pelican 1520 storage case
- 12V/5A power supply and cable
- USB 3.0 cable
- S405-XP and 780HP single-mode fibres with FC/PC to FC/APC connectors
- USB flash drive with unique wavelength calibration file
- Desiccant container filled with silica gel

5.2 Spectrometer Interfaces

The spectrometer interfaces are shown in Figure 1. The device has four mounting slots which are machined into the aluminium housing. Off-the-shelf mounting hardware (e.g. Thorlabs CL5A) can be used to secure the device onto the optical table. Make sure not to overtighten the screws as this could result in permanent deformation of the rubber feet and can also exert stress onto the housing which can negatively affect the performance of the device.
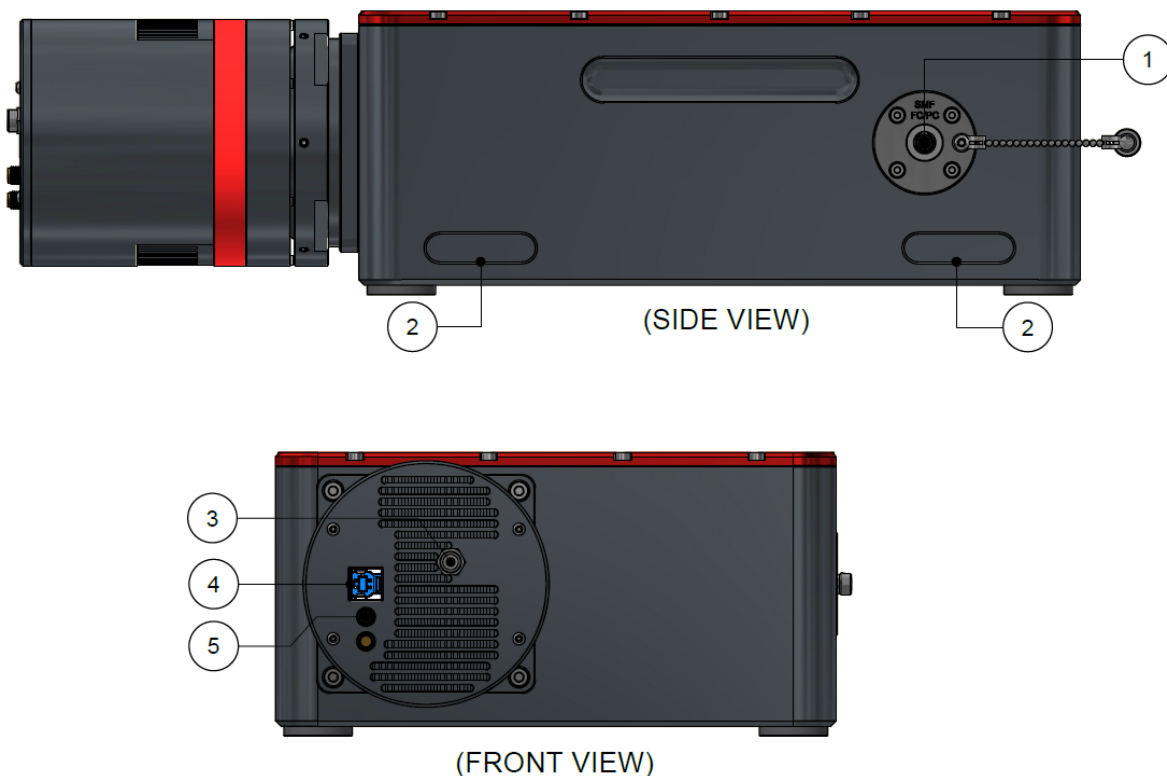

Figure 1: RS40k spectrometer ports and interfaces: (1) fibre input, (2) mounting slots, (3) 12V power, (4) USB 3.0 interface, and (5) Trigger IN/OUT. Note, the Trigger IN/OUT interface are optional and not activated by default.

5.3 Optical Fibre

The RS40k is specifically designed to work seamlessly with **single-mode fibres** that are equipped with **FC/PC connectors**. When you receive the device, it will come with two hybrid single-mode fibres (SMFs) that are suitable for your spectrometer's wavelength range. In Figure 2, you can see a depiction of commonly utilised single-mode fibres, which effectively cover the wavelength range of your spectrometer. The solid bar shows the transmission range given in the supplier's datasheet. The measured range can vary from fibre to fibre and often exceeds the theoretical limit (see hatched area).
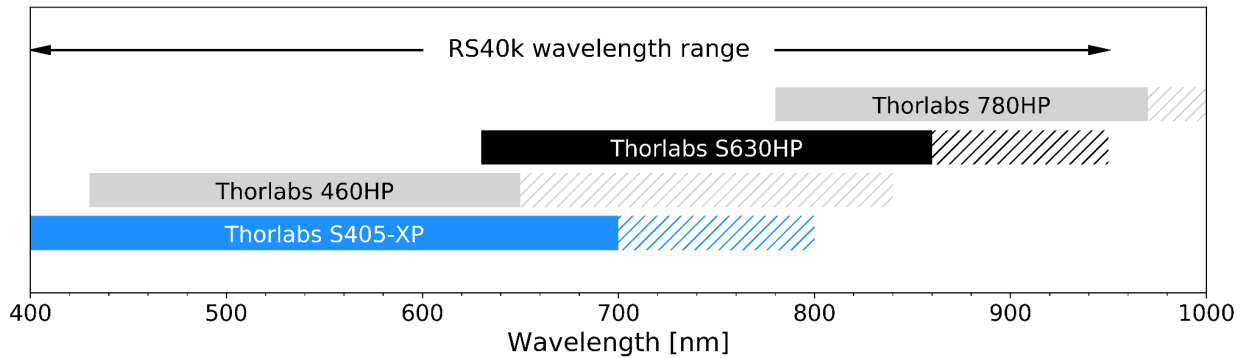

Figure 2: Selection of standard SMFs compatible with the RS40k wavelength range. The hatched area indicates the measured fibre transmission, exceeding the theoretical range.

Butt coupling FC/APC fibres to FC/PC fibres may result in light loss of up to 50%. We recommend using hybrid patch cables with FC/PC and FC/APC connectors if your experiment is based on APC fibres. Your RS40k package includes a set of hybrid patch cables (Thorlabs S405-XP and Thorlabs 780HP) which cover the 420-950 nm range.

NOTE: If your system requires fibres with FC/APC connectors please use the included hybrid patch cables to adapt your fibre system to the RS40k spectrometer.

Testing of the device has revealed that light leakage through coloured furcation tubes is able to be detected in the NIR range of the spectrum. Therefore, for best results, we recommend using fibres embedded in **black** or **metal furcation tubes** only. Alternatively, the device should be operated with the room lights switched off.

5.3.1 Cleaning Optical Fibre Connectors

The optical fibre must be thoroughly cleaned before plugging into the device. Please ensure that the fibre tip is free of scratches, dust, or any kind of dirt to achieve the best possible performance. We recommend using a fibre inspection microscope to regularly inspect the fibre-end faces at high magnification. Clean the connector ends in case dust and dirt has settled on the fibre tip. Figure 3 shows a successfully cleaned fibre surface for reference (see right image).
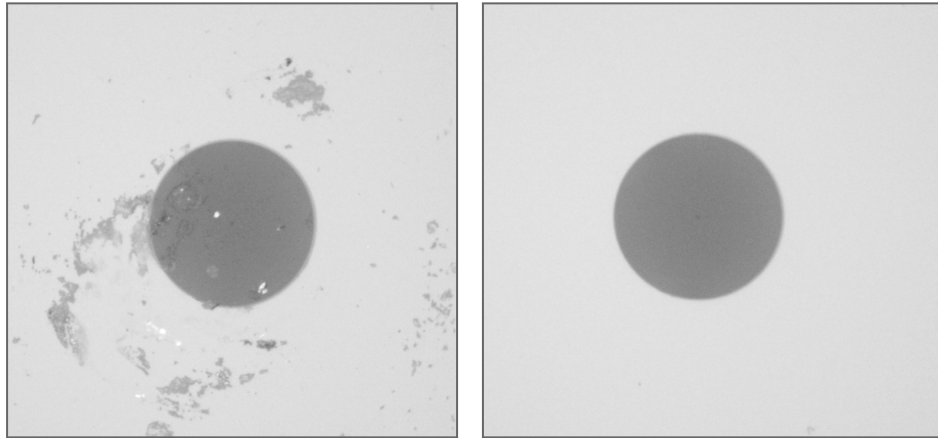

Figure 3: Microscope images of a dirty (left) and clean (right) fibre end.

6. Software

6.1 Updates + Downloads

Each spectrometer is shipped with the current version of RedSolve at production date. The latest version of the RedSolve can be downloaded from our website: www.redback.systems/downloads.

Prior to installing any updated software, you should first disconnect the spectrometer from the computer and uninstall the current software completely from the computer.

6.1.1 Check your software version

You can check what version of the RedSolve software you have installed, under the Options file menu click About (Figure 4).
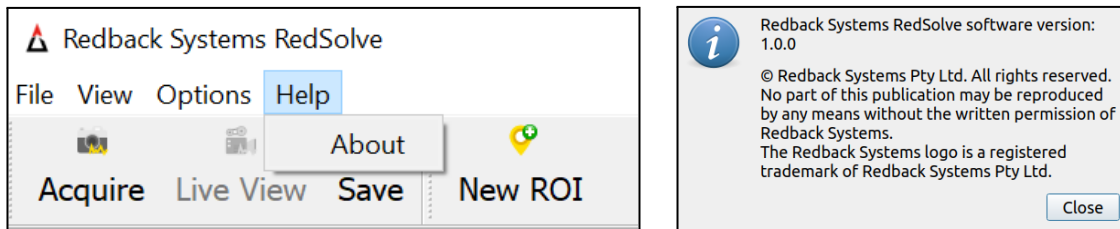

Figure 4: The About dialog is accessible from the Help menu.

6.2 Software Installation

1. Prior to commencing the installation process, terminate and exit any programs currently running on your computer.
2. Ensure the spectrometer is not connected to the computer.
3. Install the hardware driver from your USB drive
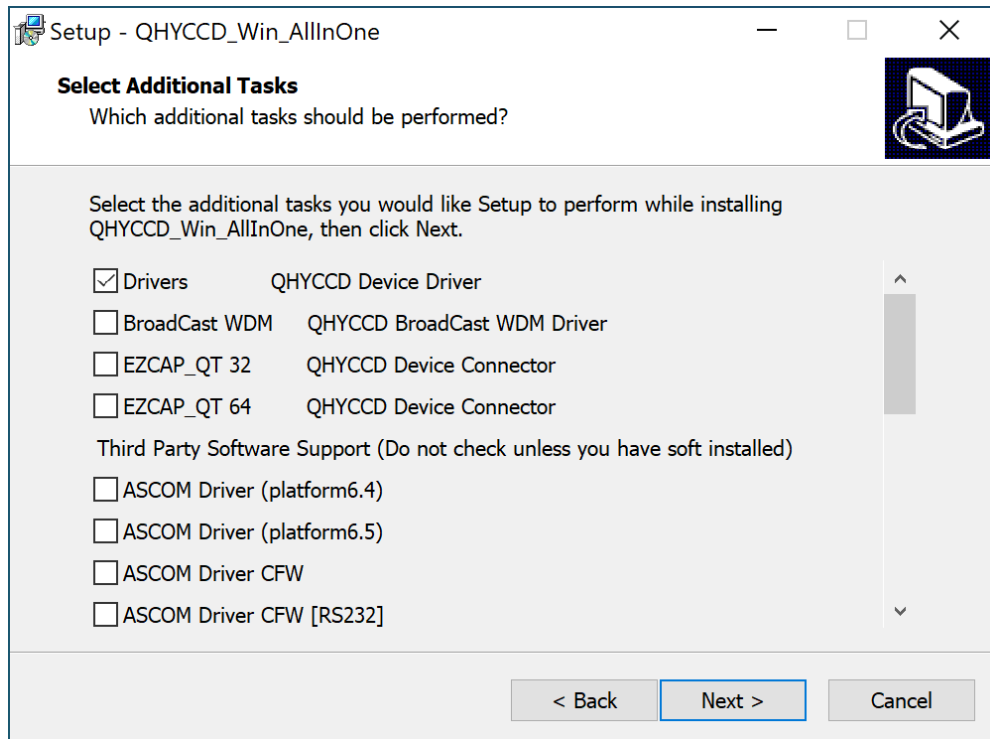4. On the install options page you only need to select the driver, as shown below:

Figure 5: The device installation wizard. Select Drivers only and proceed with the installation.

5. Download and run the latest **RedSolve Setup [version].exe** file from our website and follow the prompts presented by the install wizard.
6. After successfully installing the software, connect the RS40k spectrometer to your computer via the provided USB 3.0 cable.
7. Run RedSolve, then open the **Settings** dialog from the **Options** menu. Load the calibration file from the provided USB flash drive.

6.3 Wavelength Calibration

Each spectrometer is shipped with a unique calibration file. As part of the spectrometer installation process you must first load your calibration data from the USB drive. If no calibration file has been previously used, you will be prompted by the below dialogue. Once the calibration file is loaded you can use RedSolve to acquire data.
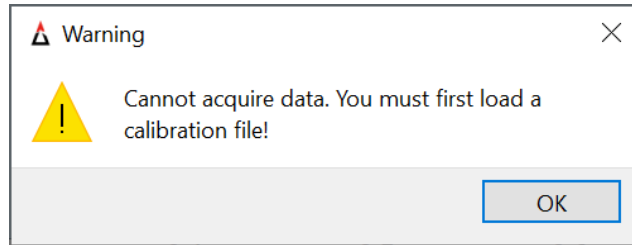

Figure 6: A warning to load the calibration file is shown on startup.

Clicking **OK** will take you directly to the settings window where you can load the included calibration file. You must click **OK** or **Apply** in the settings window to activate the calibration file. The **Settings** dialog can also be accessed from the **Options** menu.
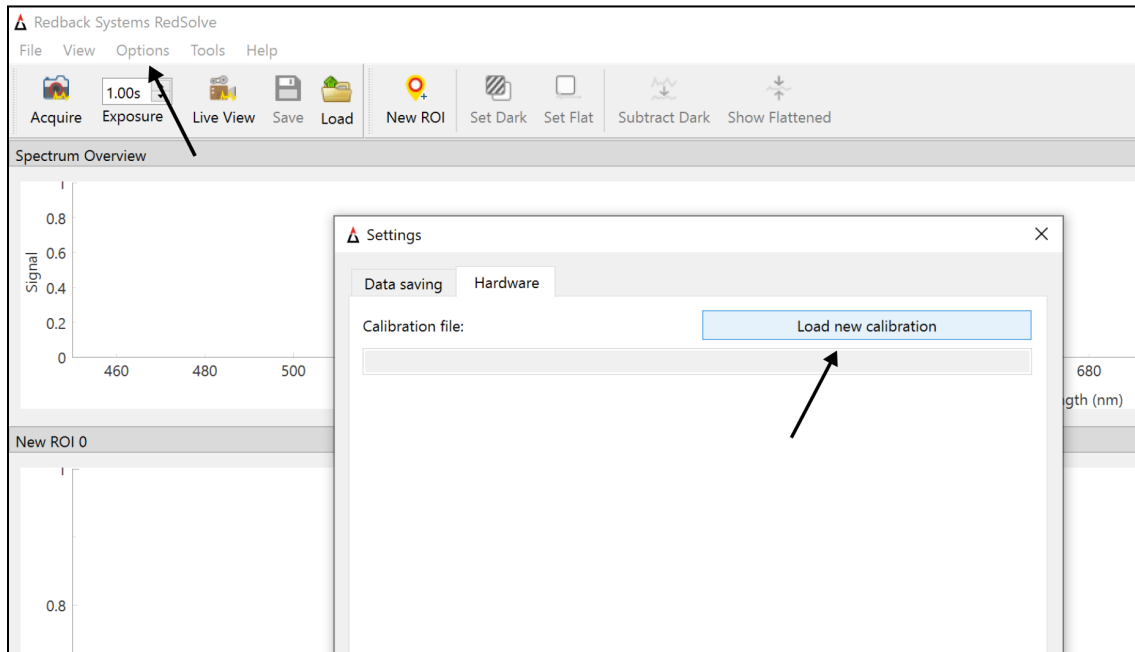

Figure 7: Load your calibration file from the USB drive into RedSolve.

6.4 User Interface

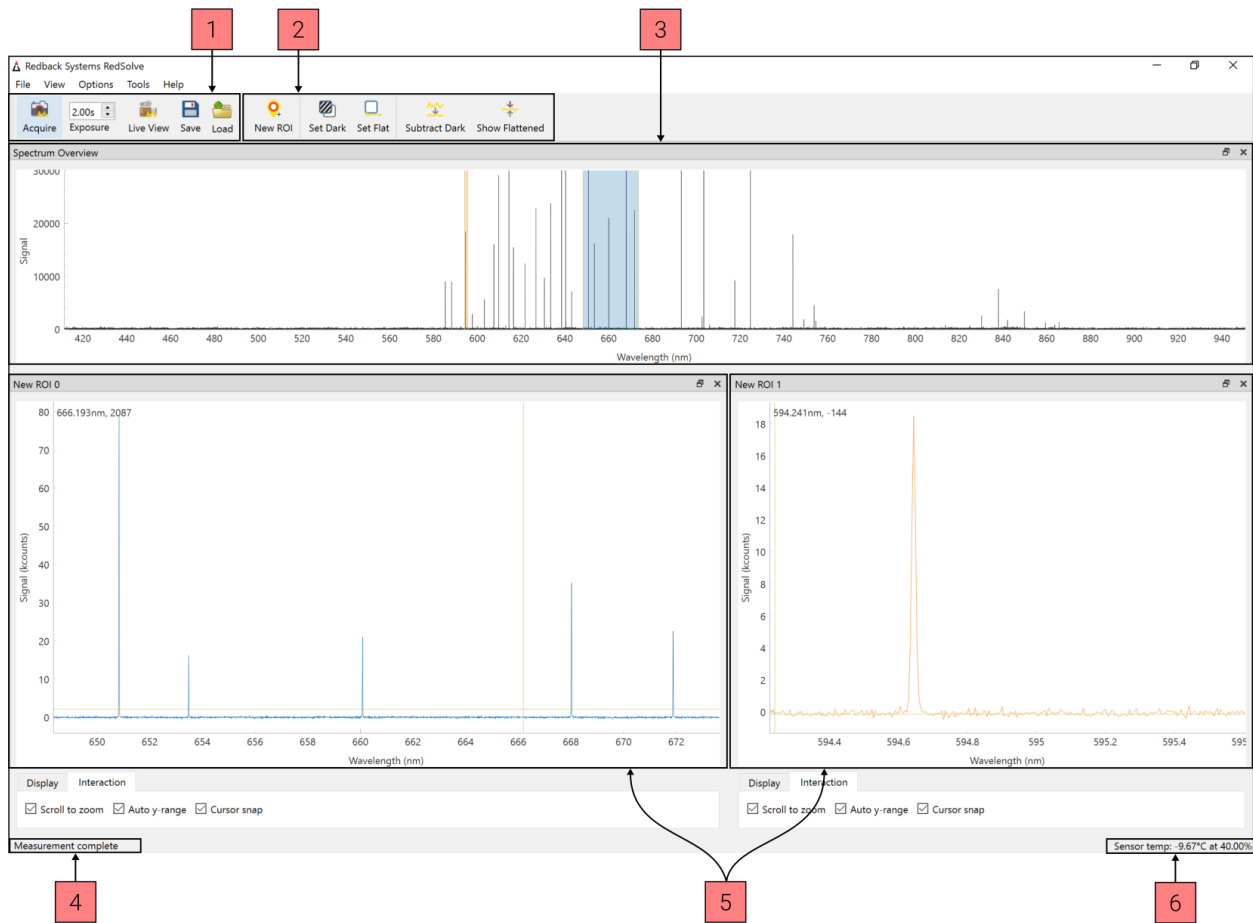Below (Figure 8) is an annotated screenshot of the RedSolve user interface.

Figure 8: The RedSolve main window.

The annotated sections of the user interface are:
1. Measurement toolbar.
2. Data visualisation toolbar.
3. Full-spectrum thumbnail plot. This panel will always display the full data range acquired.
4. Status bar.
5. Regions of Interest (ROIs). A region of interest (ROI) can be created to inspect a subset of the collected data. Multiple ROI panels can be created.
6. Detector temperature and relative humidity (for cooled detectors only).

6.4.1 Toolbar Actions

All action buttons and menu selections contain mouseover text where appropriate. The following table briefly describes the most commonly used actions.

	Acquire	Exposes the detector for the set exposure duration and converts the image into data.
	Exposure time	The detector exposure time in seconds.
	Live view	Refreshes the spectrum as quickly as possible. The refresh rate is limited by the exposure time and the data processing time. No data is recorded from Live view.
	Save	Saves the spectrum data to a *.csv file. The user will be prompted to confirm the saving directory and filename.
	Load	Load previously saved data for further exploration or processing.
	New ROI	Creates a new region of interest (ROI).
	Set Dark	Set the current data as a dark frame to allow dark subtraction.
	Set Flat	Set the current data as a spectrally flat frame to allow amplitude compensation for the echelle blaze angle modulation.
	Subtract Dark	Subtract the current dark frame from the measured data. Can be toggled on and off as desired without reacquiring data.
	Show Flattened	Apply the flat-fielding compensation for the echelle blaze angle modulation. Useful when visualising broader spectral features.

6.4.2 Spectrum Acquisition

The detector chip provided in your Redback Systems spectrometer may have higher sensitivity than other comparable spectrometers. For this reason, to avoid saturation of the detector we recommend starting your measurements with shorter exposure times, and incrementing the exposure time as required. The dashed line in the overview plot shows the maximum intensity before saturation. Breaching the exposure limit can cause light bleeding into adjacent orders which generates false signals in the spectrum. Please stay below the limit in your region of interest to avoid distorted data.

> NOTE: Stay below the saturation limit in your region of interest to avoid distorted data and artificially created peaks from light bleeding into adjacent orders.

6.4.3 Saving data

To save your data, click on the **Save** button and select the desired file directory. The complete data array will be saved in *.csv file format. Relevant metadata (e.g. exposure time, acquisition date, etc.) will be saved in the file header. A presentation-ready image showing a screenshot of the data is also saved (see example in Figure 9).
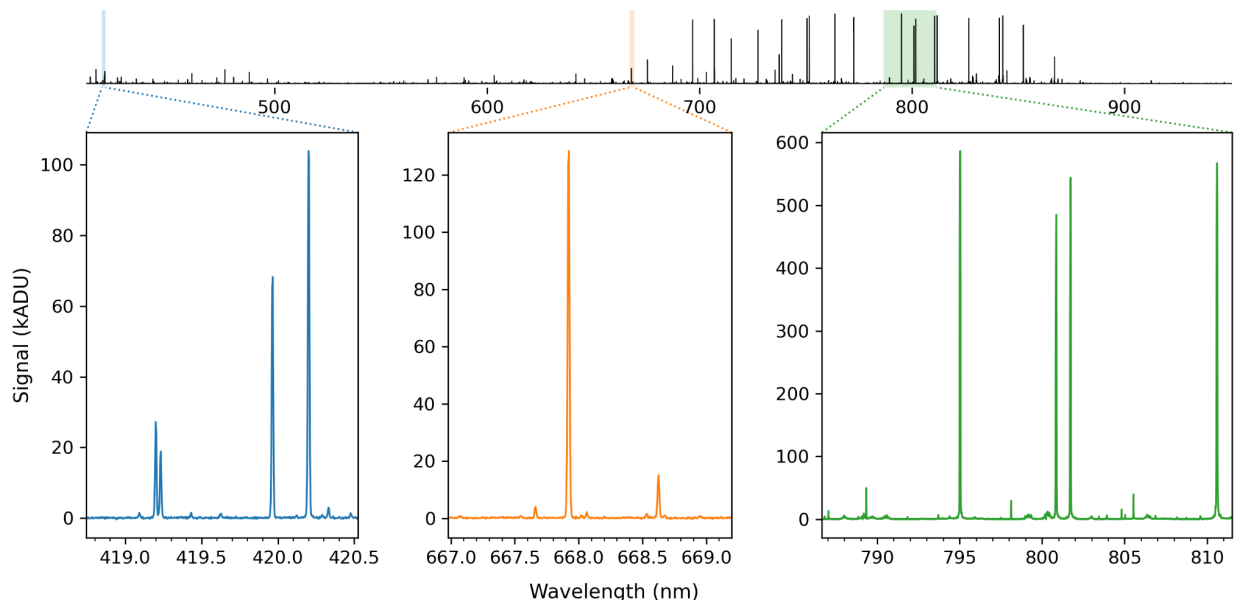
Figure 9: Example of a presentation-ready image.

6.4.4 Regions of interest (ROIs)

To give users instant access to data analysis, one can create multiple regions of interest (ROIs) in the main window. Many ROIs can be created. If the number of ROIs opened exceeds the available screen real-estate, then new ROI windows will be created as tabs.

6.4.5 Dark Screen

Selecting the **Dark screen** option from the **View** menu changes the background colour from light to dark for low-light experiments. Icons and toolbar buttons are not affected by the dark screen mode (Figure 10).
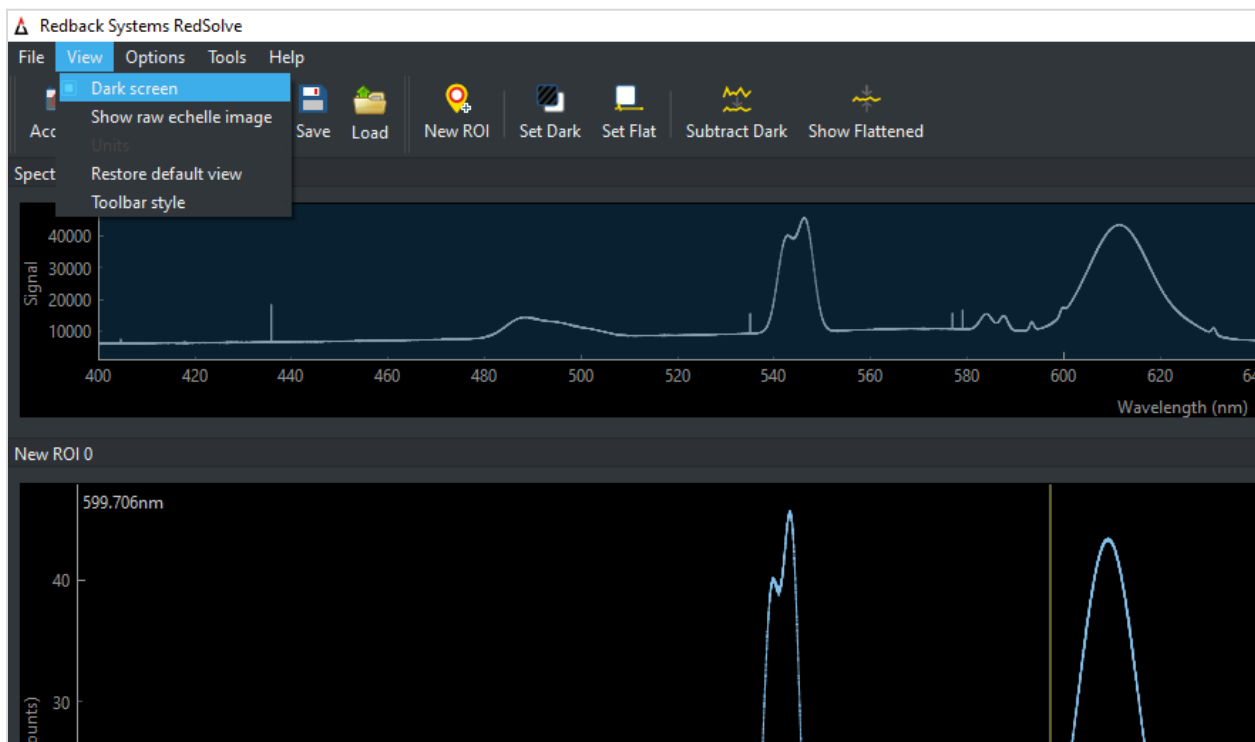
Figure 10: RedSolve dark screen mode.

6.4.6 Periodic Acquire

The Periodic Acquire function will automatically acquire data at defined intervals, and for either a fixed or infinite number of repetitions. Additionally, the user can toggle if they would like to save the data from each acquisition.

Figure 11: The Periodic Acquire menu, located within the Tools menu.

Figure 11 shows the Periodic Acquire menu. When the **Auto-refresh** button is engaged the measurement will run with the input Interval and Repeats parameters. Setting **Repeats** to "0" will continue the measurement series indefinitely. Toggling **Save on** ↻ will save the acquired data after each acquisition.

6.4.7 Dark Calibration

Modern CMOS detectors offer a number of advantages compared to more traditional CCD detectors, including increased sensitivi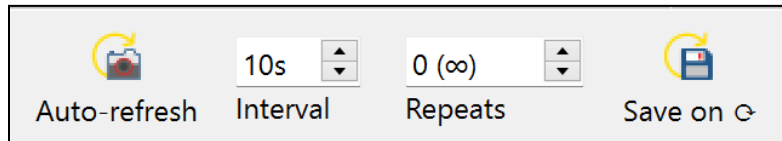ty over a wider wavelength range and faster detector read-out. Similarly to CCD detectors, their performance, however, strongly depends on temperature. As a consequence, some background counts from thermal electrons are typically recorded, even when no light hits the detector chip. First-order data reduction must be applied to all recorded images in order to remove noise associated with the CMOS detector.

The RS40k has a Peltier-cooled scientific CMOS sensor to minimise this effect. The cooler is activated in the device software RedSolve. The lowest temperature that can be reached is 40°C below ambient. We recommend operating the detector at about -10°C (set by default) to achieve the best performance and sensitivity. The sensor temperature and detector chamber humidity is always displayed in the lower right corner of the software interface (Figure 12).
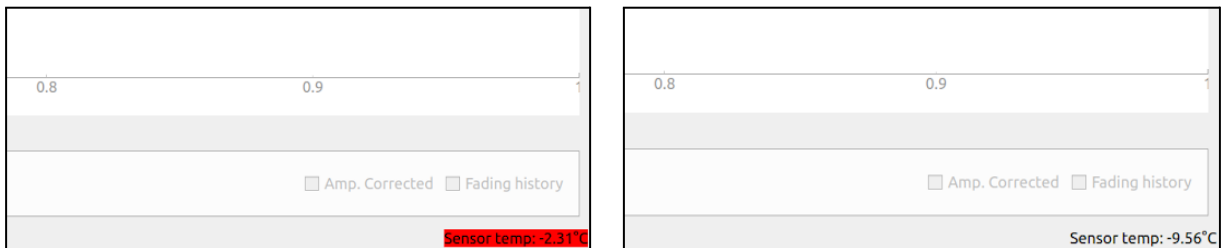
Figure 12: The sensor temperature is shown in the lower right corner of the software interface. If the sensor temperature is not within ±1°C of the set temperature it will be highlighted in red.

To remind the user, a warning will be displayed if an acquisition is attempted when the sensor has not yet cooled to the set point (Figure 13).

Figure 13: The user will be cautioned if the sensor temperature is not within ±1°C of the set temperature. Note, the default setting is -10°C.

A dark frame is recorded under the same conditions (exposure time) as the science frame. The following steps must be followed to successfully remove dark current from the science exposures:

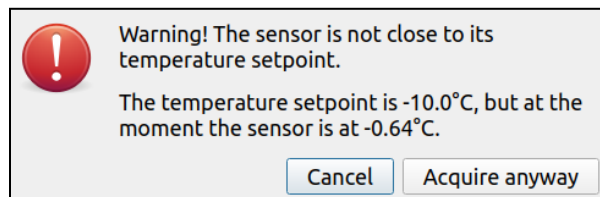1. Switch off the light source or cover the single-mode fibre input.
2. Acquire a dark frame with the same exposure time as the science frame.
3. Click the **Set Dark** button in the toolbar.

After the dark frame has been set, the **Subtract Dark** toolbar button can be toggled to automatically remove the dark signal from any recorded spectra (Figure 14).

<div style="background: red; color: white; padding: 10px;">
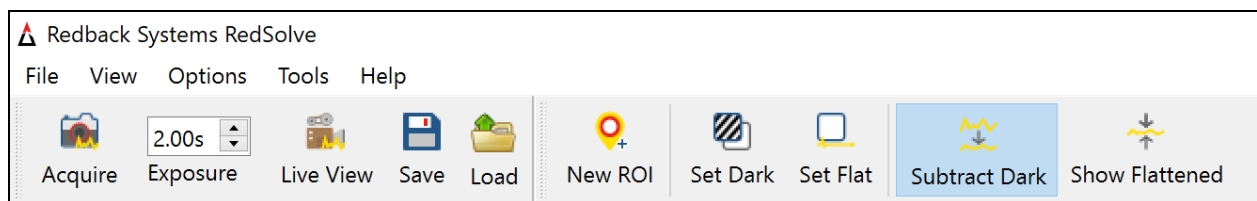<u>NOTE</u>: You must repeat steps 1-3 whenever you change the exposure time.
</div>

Figure 14: Subtract Dark icon activated.

6.4.8 Flat-Field Calibration

Spectrometers, like any optical instrument, can have non-uniformities in their detector array and optical system. These non-uniformities can lead to variations in sensitivity across different wavelengths or regions of the detector. Flat-field calibration helps to compensate for these non-uniformities by normalising the response of the device across the entire wavelength range. A complete data set acquired with the RS40k spectrometer includes a science frame with real data, a flat-field (i.e. white-light) frame, and a dark frame. The following steps describe how you acquire and process the data:

1. Switch off the light source or cover the single-mode fibre input.
2. Acquire an exposure with the same settings (exposure time, etc.) that will be used for your measurement.
3. Click the **Set Dark** button in the toolbar.
4. Uncover the fibre and take an image of a broad-band light source, preferably use a tungsten-quartz lamp (e.g. Thorlabs SLS201L or similar).
5. Acquire an exposure with an exposure setting lower than the overexposure limit (typically around 170 kcounts at 650 nm). Stay below the exposure limit over the entire range ($\rightarrow$ observe overview plot).
6. Click the **Set Flat** button in the toolbar once the white-light spectrum is acquired.

After the dark and white-light frames have been set, the **Show Flattened** toolbar button can be toggled to automatically flatten then spectrum any recorded science spectra.
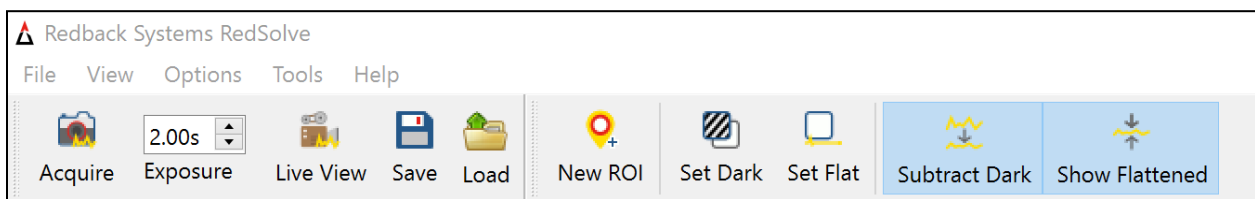

Figure 15: Subtract Dark and Show Flattened icons simultaneously activated.

6.5 Python API

It's your hardware, control it how you like. Our Python-based API makes it easy to automate measurements and seamlessly integrate spectroscopy into your workflow. Capture the data in line with post-processing and analysis.

6.6 Troubleshooting

If you encounter any issues during the installation or operation of RedSolve, visit our website for support resources. Our customer support team is also available to assist you with any questions or concerns you may have.

> **NOTE**: RedSolve software creates log files in the user appdata directory. These can be ignored by the user, but are included for the purpose of debugging.

6.6.1 Wavelength offset correction

Your RS40k wavelength calibration is factory set. Please handle the spectrometer with care as it is a precision instrument. If you believe the RS40k requires recalibration, please contact us (see Section 8).

6.5.1 High detector humidity warning

The sCMOS detector used in the RS40k spectrometer has an O-ring sealed chamber which is back-filled with argon gas to create an inert atmosphere. The O-ring seal may leak over time and water vapour is able to diffuse into the chamber. If the internal humidity is too high condensation can form on the detector cover glass when the detector is cooled below the dew point. Condensation on the detector glass manifests itself as a loss in signal strength and/or deep trenches in the recorded spectrum. RedSolve monitors the relative humidity inside the detector chamber and displays the current value at the bottom right corner. If the detector chamber humidity value exceeds a certain threshold, a warning message will notify the user. Please immediately stop using the spectrometer and follow the steps below:

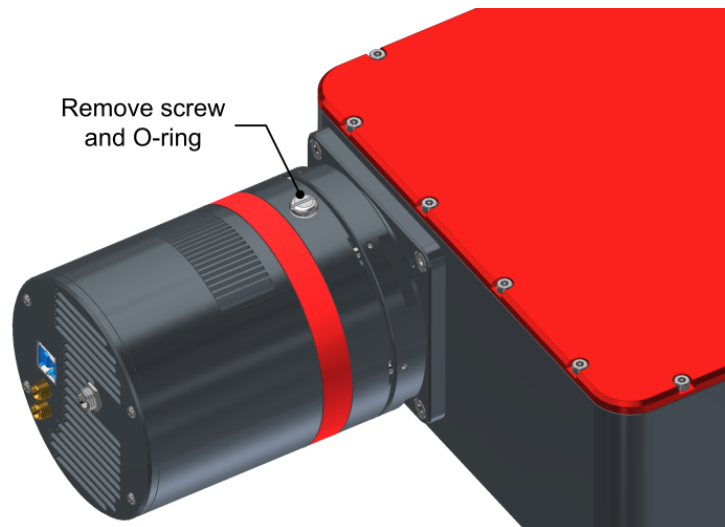1.) Remove the slotted screw on the top side of the detector as shown below.

Figure 16: CMOS detector with slotted top screw and silicone O-ring.

2.) Remove polyimide tape and plastic screw from desiccant container. Make sure the silicone O-ring is attached to the desiccant container front piece, and the mesh is on the bottom of the container when refilling with fresh or recycled silica gel.
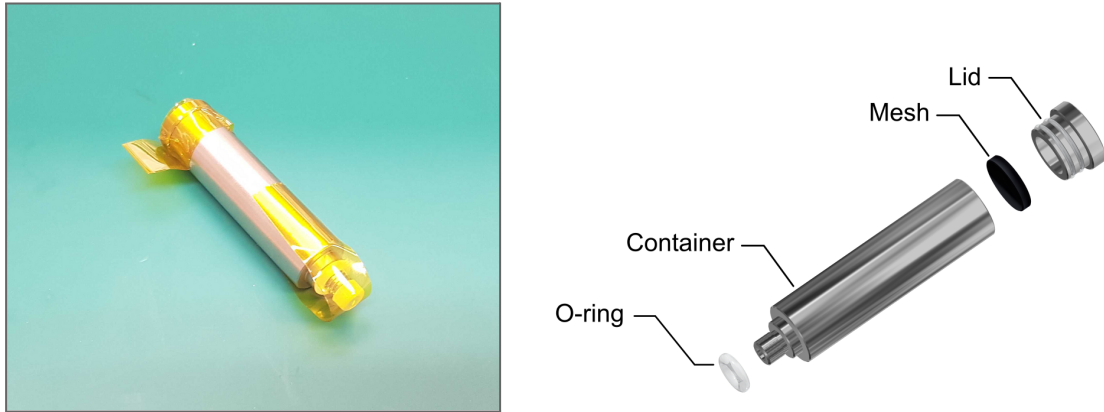

Figure 17: Photo of desiccant container (left) and container components (right).

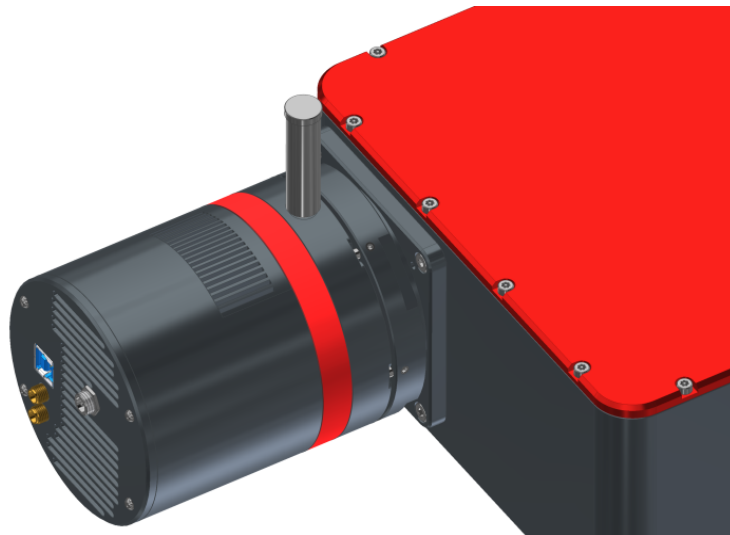3.) Install desiccant container and wait for at least 48 hours prior to using the device.

Figure 18: CMOS detector with installed desiccant container.

NOTE: The desiccant container is shipped with orange colored silica gel. The orange gel will turn green if the moisture content is above a certain percentage. You can either bake the container or refill with any dry silica gel.

7. Device properties

7.1 Optical Parameters

Spectral coverage	430-950 nm (simultaneous coverage[1]) 23,256 - 10,520 cm^{-1}
Resolving power [R=λ/dλ]	44,000-34,000 (430-950 nm)
Spectral Resolution [dλ]	~16 pm (FWHM) at 632.8 nm
Wavelength repeatability	< 20 pm
Efficiency	20% (430 nm), 54% (600 nm), 14% (950 nm)
Fibre input	standard SMF FC/PC (see Section 5.3)
Detector	cooled sCMOS, QE~95% at 580 nm
Exposure time	0.001-20 s
Acquisition rate	<5 Hz

[1] Wavelength range limited to SMF bandwidth (see Section 5.3).

7.2 Device Parameters

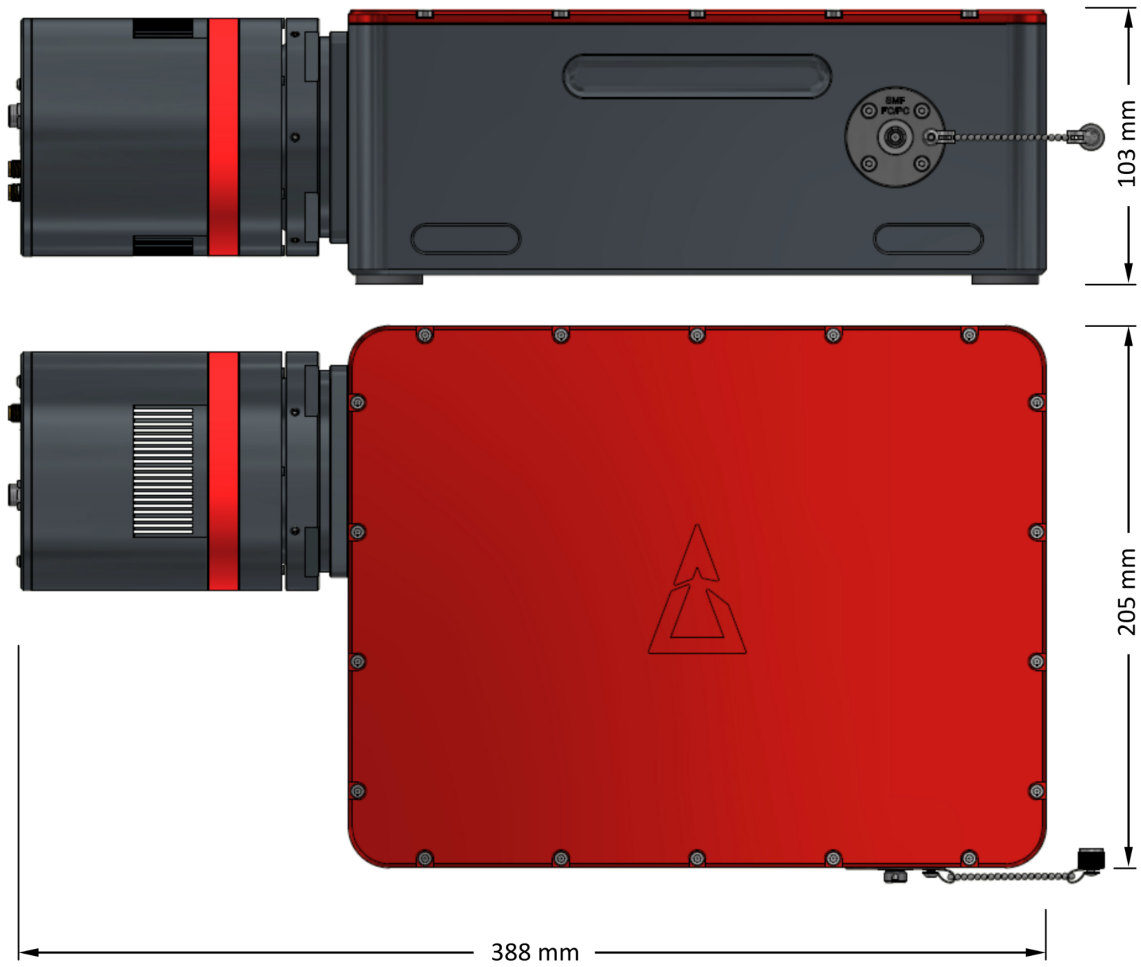|	
Weight	8.3 kg (18.1 lbs)
Temperature operating range	15-35°C
Humidity operating range	0-70% non-condensing
Power supply	12V, 5A
Computer interface	USB 3.0 (USB 2.0 compatible)

7.3 Device Dimensions

Figure 19: Dimensions of the RS40k echelle spectrometer.

8. Technical Support

Should you have any questions or require further assistance, our dedicated customer support team is here to assist you. Reach out to us via the details below. RedSolve software creates log files in the user appdata directory, which can be included in with your enquiry.

Redback Systems Technical Support

E-Mail: support@redback.systems